

TEMPERATURE CONTROL OF STIRRED TANK HEATER USING  
ON-LINE COMPUTER

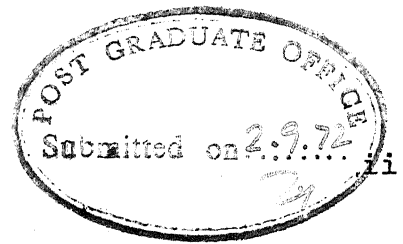
A Thesis Submitted  
In Partial Fulfilment of the Requirements  
For the Degree of  
MASTER OF TECHNOLOGY IN ELECTRICAL ENGINEERING

by

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to the  
DEPARTMENT OF ELECTRICAL ENGINEERING  
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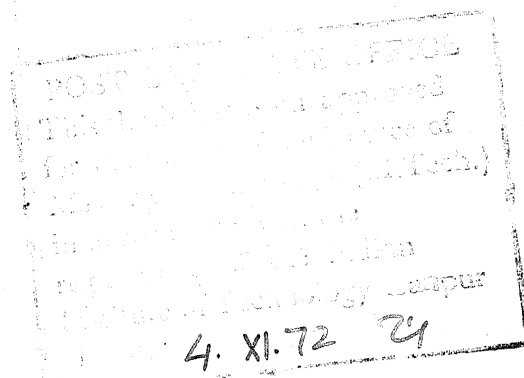
SEPTEMBER, 1972



# CERTIFICATE

This is to certify that the work on "Temperature Control of Stirred Tank Heater Using On-Line Computer" by Mr. Prahlad Kumar Srivastava has been carried out under my supervision and this has not been submitted elsewhere for a degree.

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to  
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mother



ACKNOWLEDGEMENT

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- Prahlad Kumar Srivastava

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## LIST OF ABBREVIATIONS

|            |   |
|------------|---|
| $C$        | Specific heat of liquid                         |
| $\epsilon$ | Error   |
| $\rho$     | Density of liquid                               |
| $K_C$      | Controller constant                             |
| $m$        | First order coefficient of controller           |
| $n$        | Zero order coefficient of controller            |
| $q$        | Heat input per minute                           |
| $q_s$      | Heat required to maintain set point temperature |
| $R_f$      | Feed back resistance                            |
| $R_{in}$   | Input resistance                                |
| $T_i$      | Input stream temperature                        |
| $T_R$      | Set point temperature                           |
| $T_m$      | Measured temperature                            |
| $T_{is}$   | Steady state temperature of input stream        |
| $T_s$      | Steady state temperature of tank                |
| $T$        | Tank temperature                                |
| $T_i'$     | Deviation in input stream temperature           |
| $T'$       | Deviation in tank temperature                   |
| $\tau_p$   | Process time constant                           |
| $\tau_m$   | Measuring Element time constant                 |
| $\tau_I$   | Integral time constant of controller            |
| $\tau_D$   | Differential time constant of controller        |
| $v$        | Voltage (reference) from A.D.A. output          |
| ADA        | Analog Driver Amplifier                         |

|      |                                     |
|------|-------------------------------------|
| IC   | Integrated circuit                  |
| ILSW | Interrupt device status word        |
| INT  | Interrupt                           |
| LWA  | Level word area                     |
| MIC  | Master interrupt control            |
| NSI  | Next sequential instruction         |
| PSC  | Program sequence control            |
| PISW | Process Interrupt status word       |
| TIBA | Table of interrupt branch addresses |

## ABSTRACT

The contents of this thesis presents the work done to interface the "stirred tank heater" to IBM 1600 for the control of tank temperature. This represents a part of the work towards the use of digital computer for process control. Variable gain differential amplifier and 'Power Control Units' are designed for this purpose. The programs are written to service the interrupt, from process terminals, process data acquisition and control. Proportional integral control scheme has been used in the program which operates in time shared mode.

## CHAPTER 1

### INTRODUCTION

The digital computers have been successfully employed as data processing aids in business and management for a long time. The design of computer, which will be useful for control of industrial processes and other Real-Time applications was suggested nearly a decade ago. Enough experimentation was done to develop capability of computer to operate in "Real-Time" and with the speed and accuracy to control critical processes safely.

Experience has shown that the use of computer as a tool for process-control has the potential to increase process output, raise efficiency, improve quality and cut operating cost.

IBM 1800 is a computer designed for process-control and other real-time applications, such as data logging, air-line reservation system, air-craft and missile control etc. It is a third generation computer, employing solid-state technology. The system is compatible to IBM 360.

Classical control methods make use of analog controllers for controlling parameters of a physical process. The recent developments have led to advanced control system of following types.

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1. Closed Loop Supervisory Control: It keeps track of "set point\*". It issues commands to operator to take necessary action.
2. Direct Digital Control: The computer itself provides analog backup to keep track of set point by itself. DDC is becoming increasingly attractive to analog control these days.

### 1.1 PROBLEM SPECIFICATION

The problem is to control the temperature in a 'Stirred Tank Heater' using Direct Digital Control technique. IBM 1800 is used for this job. The transducer attached to the process converts temperature to an electrical signal. The electrical signals obtained are converted to digital form using Analog to Digital Converter provided with the system.

The difference between the set point and measured value of temperature is an error signal. The error signal is an input to the control program. The computer

---

\* Set Point: It is the desired value of certain process parameter. In the present experiment, it is the required temperature of the tank.



calculates the required current or voltage to be applied to the heater which in turn lowers or increases the temperature of the tank as desired to maintain the temperature of the tank nearly constant. The variation allowed depend on the sensitivity of the transducer used to sense temperature and the accuracy of A to D conversion.

## 1.2 PROGRAMMING SYSTEM USED<sup>1,16</sup>

The programming system used for this application is "Time Sharing Executive System". A brief description of this system is given below.

This system divides the memory into two parts.

1. Executive: It contains all the required system programs and few important programs of the user which have to be executed on the priority basis.
2. Variable Core: This area is available for the processing of process \* and non-process \*\* job.

---

\* Process Job: These are the type of jobs, which require computer attention in 'Real-Time' and are run at definite intervals of time. These jobs in general get the priority over non-process job for execution.

\*\* Non-process Job : These are some application programs like pay-roll computation and other data processing work which done when process program is not under execution.

Whenever some process program is being executed, and an interrupt arrives from the process, non-process program is saved in non-process save area (defined on the disk) and process job is brought into execution. When an interrupt arrives while processing a process job, it is recorded and queued depending on its priority. On the completion of process program in execution, next process job waiting at the top of queue is brought into execution. If no process job is available non-process program is executed.

The advantage of TSX<sup>16</sup> system is that the tailored system provides the time sharing facility and the Executive occupies relatively smaller amount of core (than MPX)<sup>17</sup>.

## CHAPTER 2

### CONTROL SCHEME

2

#### 2.1 BASIC METHODS OF TEMPERATURE CONTROL

There are, in general, three methods to control the temperature of masses.

1. The thermal resistance between a heat source and a heat sink is controlled; the control can be accomplished by either a permanent or time varying change for any combination of conduction, convection, or radiation heat transfer.
2. The heat dissipation at a controlled mass or on a thermal path between the controlled mass and its heat sink is regulated, either by a permanent change or in a continuously or discretely varying way.
3. The heat absorption capacity of heat sink is controlled.

#### 2.2 PHYSICAL LAYOUT OF THE SYSTEM

The experiment being a demonstration set-up for the control of the process parameter, a simple scheme is selected.

The present experiment demonstrates the control of temperature in a stirred tank.

The second approach, described in Section 2.1 is utilized to control the temperature in a "stirred tank heater".

Figure 2.1.1 represents sketch of the apparatus. Water stream at room temperature  $T_i$  enters on well stirred tank at a constant flow rate  $w$ . The heated water leaves the tank at the same flow rate. It is desired to maintain the temperature in the tank at  $T_R$  by means of controller. If the indicated tank temperature  $T_m$  differs from the desired temperature  $T_R$  the controller senses the difference or error,  $\epsilon = T_R - T_m$  and changes the heat input in such a way as to reduce the magnitude of  $\epsilon$ . The heat is supplied to the tank, by dipping an immersion heater in the tank. The flow of electrical power to the heater is regulated by a control unit, which regulates the current to a resistance heating element.

To maintain a constant flow and discharge to and from the tank, pumps have been used in input and output lines. To regulate the flow the valves are

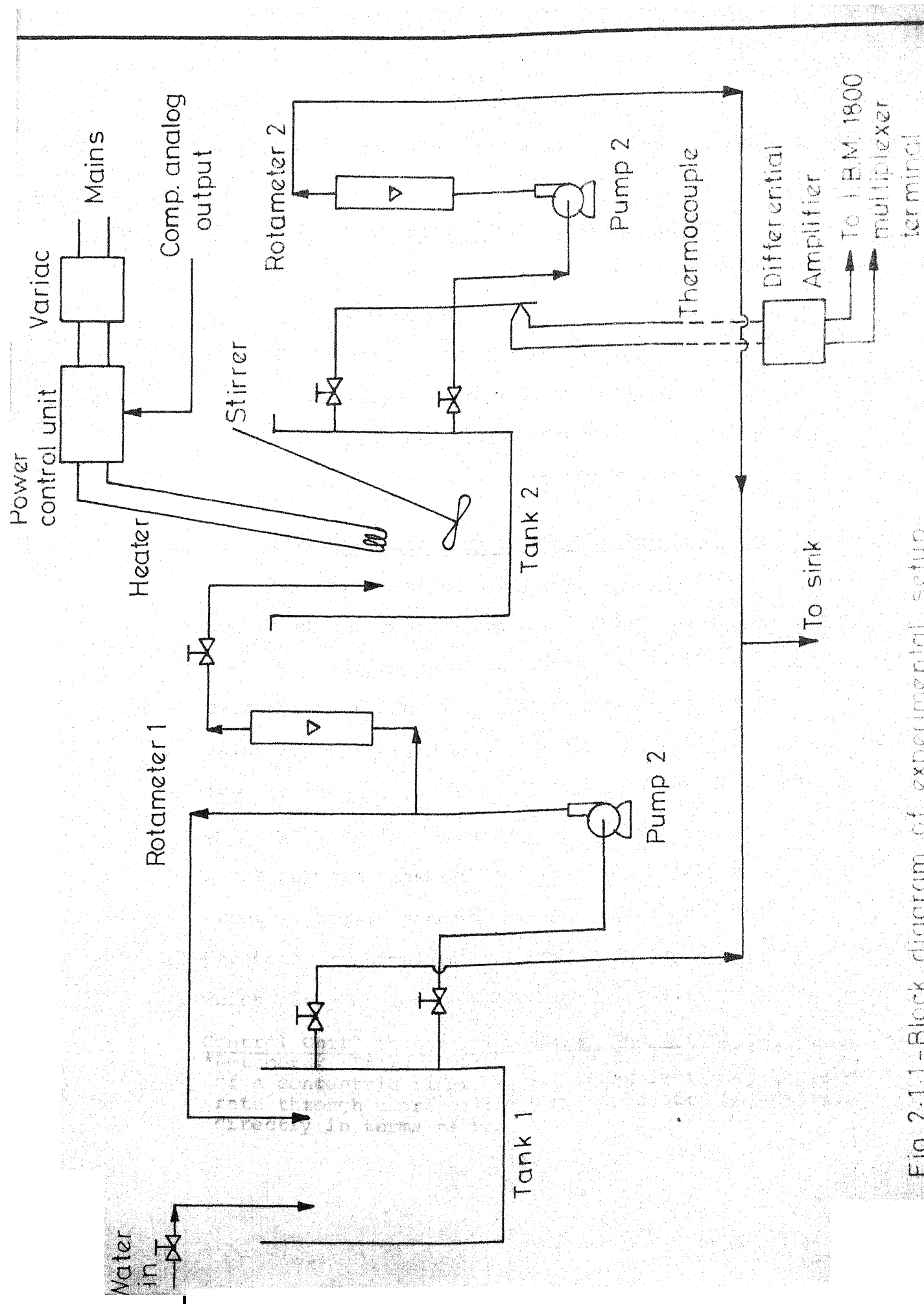


Fig. 2.1.1-Block diagram of experimental setup.

provided in the input and output lines. The Rotameters\* attached in the lines indicate the flow in u.s. gallons/minute.

### 2.2.1 Components of the control system:

The system shown in Figure 2.11 is divided into following components.

1. Process (stirred tank heater).
2. Measuring Element (Thermocouple)
3. ON-LINE Computer (IBM 1800)
4. Final Control Element (Thyristor controlled Power Control Unit)

### 2.2.2 Control loop representation in blocks

For computational purposes, it is convenient to represent the control system of Figure 2.11 by means of block diagram shown in Figure 2.2.2. The control system is a closed loop system because the measured value of controlled variable (temperature) is fed to computer. This value in-turn is read and compared with set point value. If there is any difference between measured value and set point value, an error signal is generated. This error is used as a parameter to simulated controller in the computer, which gives analog output which is utilized by "Power Control Unit" to control power to the system in such

\*Rotameter: It is a variable area flowmeter. The edge of a concentric float, serves as an indicator of flow rate through a pre-calibrated scale attached to it, directly in terms of flow units.

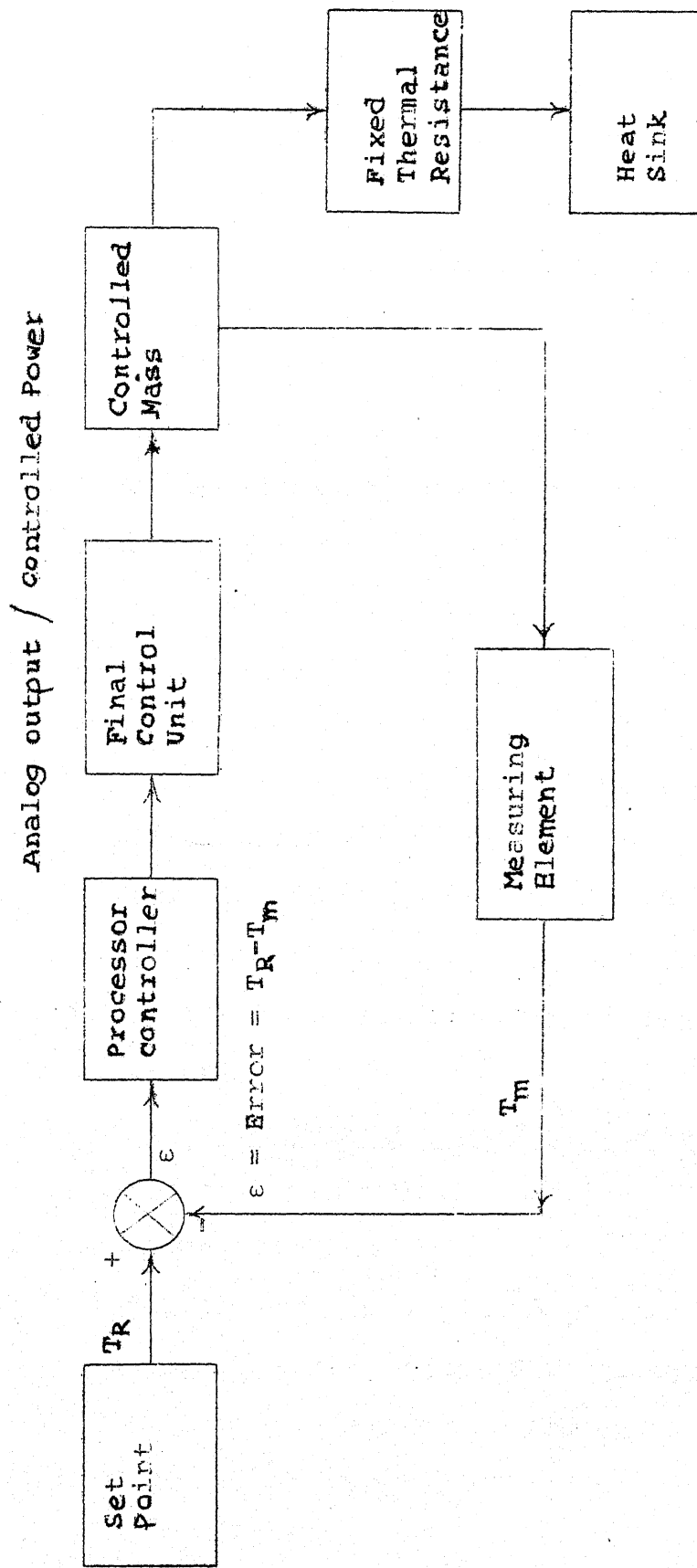


FIG. 2.2.2 Block Diagram of Control System.

a way as to return the controlled variable to set point.

### 2.2.3 Mathematical Model of the System <sup>3</sup>

The mathematical model of the system is built to calculate the response of the system. The overall transfer function of the control loop is determined to find out the stability of the system. It also helps to find out the coefficients of general control equation for optimal control.

The effect of sampling in DDC is to produce an steady state error. It also superimposes noise on the signal. The sampling speed has to be adjusted such that the noise introduced is minimum and at the same time the deviation from 'set point' is also reduced.

To calculate the overall transfer function of the process, the transfer functions of individual blocks are to be calculated.

### 2.2.4 Transfer Function of the Process

To calculate the transfer function of the process following assumptions are made

1. Water flow in the input and output lines are constant and adjusted to be equal.
2. Flow rate of heat 'q' is instantaneously available and independent of temperature in the tank.



3. The radiation losses have been neglected.

Applying unsteady state energy balance in the heating tank gives

$$q + W.C.(T_i - T_o) - W.C.(T - T_o) = \rho.C.V.\frac{dT}{dt} \quad (1)$$

where

$q$  is heat added instantaneously

$w$  is flow rate (mass/time)

$T_i$  is input water temperature

$T$  is output water temperature

$T_o$  is reference temperature

$\rho$  is density of liquid

$V$  is volume of liquid in the tank.

at steady state,  $\frac{dT}{dt}$  is zero, so equation (1) can be written as

$$q_s + WC(T_{is} - T_o) - WC(T_s - T_o) = 0 \quad (2)$$

affix 's' represent steady state value of these parameters.

Subtracting (2) from (1) we get

$$(q - q_s) + WC[(T_i - T_{is}) - (T - T_s)] = \rho CV \frac{d}{dt}(T - T_s) \quad (3)$$

introducing deviation variables

$$Q = q - q_s \quad (4)$$

$$T_i' = T_i - T_{is} \quad (5)$$

$$T' = T - T_s \quad (6)$$

$$Q + WC (T'_i - T') = \rho CV \frac{dT'}{dt} \quad (7)$$

Taking laplace transform

$$Q(s) + WC [T'_i(s) - T'(s)] = \rho CV s T'(s) \quad (8)$$

or

$$T'(s) [1 + \frac{\rho V}{W} \cdot s] = \frac{Q(s)}{WC} + T'_i(s) \quad (9)$$

or

$$T'(s) = \frac{(\frac{1}{WC})}{1 + \tau_p \cdot s} Q(s) + \frac{1}{1 + \tau_p \cdot s} T'_i(s) \quad (10)$$

where

$$\tau_p = \frac{\rho V}{W} = \text{time constant of process.}$$

Assuming that input water temperature to the tank remains constant for all practical purposes. This means  $T'_i(t) = 0$ , hence transfer function can be written as

$$\frac{T'(s)}{Q(s)} = \frac{(1/WC)}{1 + \tau_p \cdot s}$$

where

$$\tau_p = \frac{\rho V}{W} .$$

#### 2.2.5 Measuring Element:

Thermocouple is selected as temperature measuring device. The thermocouple which senses the tank temperature  $T$  and transmits signal  $T_m$  to the computer, exhibits some dynamic lag. The dynamic lag is observed to be the first order. The transfer function of first order system is equal to

$$\frac{T_m'(s)}{T'(s)} = \frac{1}{\tau_m s + 1} \quad (11)$$

where

$T_m' = T_m - T_{ms}$  and  $T' = T - T_s$  (parameters with suffix 's' represent steady state values).

Since the time constant of thermocouple is much smaller than the time constant of the process to we can neglect it. Thus the transfer function reduces to

$$G_m = \frac{T_m'(s)}{T'(s)} = 1 \quad (12)$$

#### 2.2.6 Controller and Final Control Element<sup>4</sup>

For convenience the blocks representing the controller and final control element have been combined into one block. The relationship for a proportional controller is

$$q = K_C \cdot \varepsilon + \frac{K_C}{\tau_I} \int_0^t \varepsilon dt + K_C \cdot \tau_D \frac{d\varepsilon}{dt} + q_s \quad (13)$$

for P.I.D. Control

$$\frac{Q(s)}{\varepsilon(s)} = K_C \left( 1 + \tau_D s + \frac{1}{\tau_I s} \right) \quad (13A)$$

Some work has been done in DDC area. Following are the conclusions of the work.

1. Proportional action can not be used in direct digital control as it results in random walk of controlled variable (Temperature) about the set point.
2. At least two term control should be used, e.g., Proportional Integral Control.
3. The derivative term does not improve the performance. Bernard<sup>4</sup> states that derivative term has damping effect as sampling interval is increased.

So far our purpose, proportional integral control is used. The transfer function of controller is

$$G_C = \frac{Q(s)}{\epsilon(s)} = K_C \left( 1 + \frac{1}{\tau_I \cdot s} \right). \quad (13c)$$

#### Control Algorithm

General equation for PI control is

$$Q = q_s + K_C \left[ \epsilon + \frac{1}{\tau_I} \int \epsilon dt \right]$$

where

$q_s$  = heat supplied at steady state

$\tau_I$  = integral time constant

$K_C$  = proportional time constant

$\epsilon$  = error

$Q$  = heat to be supplied

Expressing the above equation in difference equation form<sup>5</sup>

$$Q_n = q_s + K_c [E_n + \frac{\tau}{\tau_I} \Sigma E_n] \quad (14)$$

$\tau$  = sampling period

$E_n$  = Current error

$Q_n$  = Currently amount of heat supplied to minimize error.

Suppose we always supply heat required to maintain steady state. For fluctuations in process, we want to determine heat change required to control the process.

$$\begin{aligned} \Delta Q_n &= Q_n - Q_{n-1} \\ \Delta Q_n &= K_c [(E_n - E_{n-1}) + \frac{\tau}{\tau_I} E_n] \end{aligned} \quad (15)$$

Hence the total amount of heat  $Q_n$  given to tank after nth sampling

$$Q_n = Q_{n-1} + \Delta Q_n \quad (16)$$

to compensate for the deviation occurred between (n-1)th and nth sampling period.

The control loop is finally represented as shown in Figure 2.2.3.

## Processor Controller

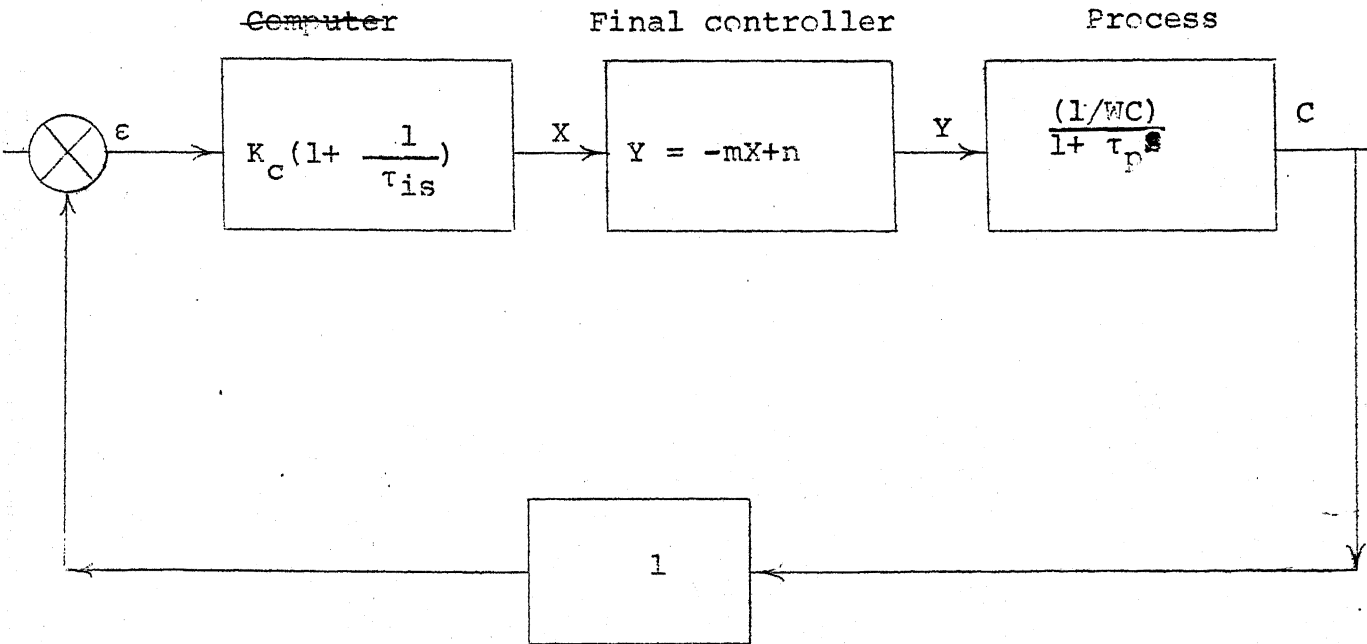


FIG. 2.2.3: Final representation of control loop.

### 2.2.7 Determination of Criterion for Optimal Control:

The value of various constants in control equation are determined, such that error is minimized. The criteria for optimal control can be mathematically represented by

$$I = \int_{-\infty}^{\infty} \epsilon^2 dt \text{ is minimum.}$$

The error is represented by

$$\epsilon = R - C$$

The controlled variable  $C$  is mathematically represented by,

$$C = [-m \{ \epsilon \cdot K_C (1 + \frac{1}{\tau_i \cdot S}) \} + n] \frac{\frac{1}{W \cdot C}}{\tau_p \cdot S + 1}$$

Thus,

$$\epsilon = R - [ -m \{ \epsilon \cdot K_C (1 + \frac{1}{\tau_i \cdot S}) \} + n] \frac{\frac{1}{W \cdot C}}{\tau_p \cdot S + 1}$$

$$\epsilon = R + \epsilon \cdot m \cdot K_C (1 + \frac{1}{\tau_i \cdot S}) \frac{\frac{1}{W \cdot C}}{\tau_p \cdot S + 1} - n \frac{\frac{1}{W \cdot C}}{\tau_p \cdot S + 1}$$

$$\epsilon = \frac{R - n \cdot \frac{\frac{1}{W \cdot C}}{\tau_p \cdot S + 1}}{1 - m \cdot K_C (1 + \frac{1}{\tau_i \cdot S}) \frac{\frac{1}{W \cdot C}}{\tau_p \cdot S + 1}}$$

$$\epsilon = \frac{R \cdot W \cdot C \cdot \tau_i \cdot S \cdot (\tau_p \cdot S + 1) - n}{W \cdot C \cdot \tau_i \cdot S^2 + \tau_i \cdot S (W \cdot C - m \cdot K_C) - m \cdot K_C}$$

If we give a step to the system, then

$$R = 1/S$$

So,

$$\begin{aligned} \epsilon &= \frac{W \cdot C \cdot \tau_i \cdot (\tau_p \cdot S + 1) - n}{W \cdot C \cdot \tau_i \cdot S^2 + \tau_i \cdot S (W \cdot C - m \cdot K_C) - m \cdot K_C} \\ &= \frac{W \cdot C \cdot \tau_i \cdot \tau_p \cdot S + (W \cdot C \cdot \tau_i - n)}{W \cdot C \cdot \tau_i \cdot \tau_p \cdot S^2 + \tau_i \cdot S (W \cdot C - m \cdot K_C) - m \cdot K_C} \end{aligned}$$

The integral square error is represented as,

$$I = \int_{-\infty}^{\infty} \epsilon^2 \cdot dt = \int_{-\infty}^{\infty} \epsilon \cdot \epsilon \cdot dt$$

This is represented in frequency plane as

$$I = \frac{1}{2\pi j} \int_{-\infty}^{\infty} \epsilon(s) \cdot \epsilon(-s) \cdot ds.$$

The solution to this problem has been worked out and is of the form:

$$I = \frac{C_1^2 d_0 + C_0^2 d_2}{2d_0 d_1 d_2}$$

For our problem

$$C_0 = W.C. \tau_i \cdot \tau_p$$

$$C_1 = (W.C. \tau_i - n)$$

$$d_0 = W.C. \tau_i \cdot \tau_p$$

$$d_1 = (W.C. - m K_C) \cdot \tau_i$$

$$d_2 = -m K_C$$

$$\begin{aligned} I &= \frac{(W.C. \tau_i - n)^2 \tau_p W.C. \tau_i + (W.C. \tau_i \cdot \tau_p)^2 (-m K_C)}{2 W.C. \tau_i^2 \cdot \tau_p (W.C. - m K_C) (-m K_C)} \\ &= \frac{(W.C. \tau_i - n)^2}{2 \tau_i (W.C. - m K_C) (-m K_C)} + \frac{\tau_p}{2 (W.C. - m K_C)} \\ &= \frac{W^2 C^2 \tau_i^2}{2 (W.C. - m K_C) (-m K_C)} - \frac{n \cdot W.C.}{\tau_p (W.C. - m K_C) (-m K_C)} \\ &\quad + \frac{n^2}{2 \tau_i (W.C. - m K_C) (-m K_C)} + \frac{\tau_p}{2 (W.C. - m K_C)} \end{aligned}$$

The value of  $K_C$  and  $\tau_i$  is determined from minimum error considerations from following considerations



$$\frac{\partial I}{\partial K_C} = 0 \quad (1)$$

$$\frac{\partial I}{\partial \tau_i} = 0 \quad (2)$$

CONDITION 1: From equation (1)

$$\begin{aligned} & - \frac{W.C \tau_i}{2 \tau_p} \left[ \frac{1}{(W.C - m K_C)(-m K_C)} \right]^2 - m(-m K_C) + -m(-m K_C) \\ & - \frac{n W.C}{\tau_p} \left[ \frac{1}{(W.C - m K_C)(-m K_C)} \right]^2 \{ + 2m K_C \} \\ & + \frac{n^2}{2 \tau_i \tau_p} \left[ \frac{-1}{(W.C - m K_C)(-m K_C)} \right]^2 \{ 2 m K_C \} \\ & + \frac{\tau_p}{2} \left[ \frac{1}{(W.C - m K_C)} \right]^2 (-m K_C) \\ & \frac{1}{(W.C - m K_C)^2} \left[ - \frac{W.C \tau_i}{\tau_p \cdot m K_C} - \frac{2n.W.C}{\tau_p \cdot m K_C} - \frac{n^2}{\tau_i \cdot \tau_p m K_C} - \frac{m \cdot K_C \cdot \tau_p}{2} \right] = 0 \end{aligned}$$

For this consideration

$$K_C = \infty$$

We select  $K_C = 1000$  onwards for practical purposes

CONDITION II: From equation (2)

It gives

$$W^2 C^2 \tau_i = \frac{n^2}{2 \tau_i^2}$$

$$\tau_i^3 = \frac{n^2}{2 W^2 C^2}$$

$$\tau_i = \frac{1}{3} \sqrt[3]{\frac{n^2}{2 W^2 C^2}} = \frac{1}{3} \sqrt[3]{\frac{n^2}{2 W^2}}$$

The above values of  $K_c$  and  $\tau_i$  are used in the control routine.

#### 2.4 SOFTWARE ASPECTS OF THE SCHEME:

The idea of the ON-LINE control is that periodically, the program to measure temperature and control it should be executed. The time interval at which the program is to be executed is set by the "count" routine so that at set time interval, the programmed interrupt occurs and the program is loaded into memory. This operation is initiated by the process interrupt (PISW bit 03).

The control program "CNTRL" have been stored as a subroutine on the disk. For this routine the response time is not a critical problem. The program PMESS is an interrupt servicing core load and permanently resides on disk. The subroutine "INT 1" which calls "PMESS" core load is built in as a part of executive. As the interrupt arrives, this routine is immediately serviced.

##### 2.4.1: Initiation of Program Execution:

The program is initiated by the process interrupt at PISW (group 00, bit 03) when the interrupt occurs in the system, the source of interrupt is determined by the Executive. If the source of interrupt is found to be process interrupt bit 03, the SUBROUTINE 'INT 1' included in the executive services the interrupt. At the completion of the interrupt service, following action will be

taken depending on the status of the system.

1. The interrupting program is queued depending on its priority of a process job is currently under execution. At the completion of this job, the core load waiting at the top of the queue at this time is loaded onto memory.
2. If a nonprocess job is in execution, the job in execution is saved onto disk in interrupt save area and the main line program PMESS which is stored in the disk in core image form is loaded in the core memory.

The main line program ANLOG as it is executed performs the following steps sequentially.

1. Asks for "Set point" temperature value? This value is supplied through key-board (1816) input.
2. Asks for ambient temperature. It is supplied through key board input.
3. Depending on set point temperature and ambient temperature and max. capacity of heater max. flow rate allowed is calculated and operator is asked to adjust the flow rate less than max. flow rate. Operator adjusts the flow rate and feeds the value of adjusted flow rate to computer through key board and calls program ANLOG.

4. It reads the analog voltage at multiplexer point 01 and its value is stored in some area. The binary value in A.D.C. register is converted to the exact voltage value.
5. With the help of 'Calibration Curve' of thermocouple, the analog voltage read is converted to its equivalent temperature value.
6. The difference between the 'Set-Point' temperature and measured temperature gives the error signal.
7. Now the main line program 'ANLOG' calls the subroutine 'CNTRL' control which calculates the output value depending on the magnitude of error signal.
8. The digital output obtained from the above step is converted to equivalent analog voltage using ~~xx~~ a D/A converter. This conversion is achieved by the routine 'OUTPT' which makes use of system routine 'DACP'.
9. The main routine ANLOG is executed after specified interval, so that a corrective action is taken before a major deviation of temperature occurs from its 'Set Point' value. This is achieved by the 'COUNT' routine included in the executive.

## CHAPTER 3

### HARDWARE DEVELOPMENT

#### 3.1 MEASUREMENT OF TEMPERATURE <sup>6,7,8.</sup>

Thermocouple<sup>\*</sup> is used for the measurement of temperature of the tank. The hot junction is kept in the tank, where the temperature is to be measured. The electro-motive-force (e.m.f.) generated by the temperature change at the hot junction of the thermocouple is measured with respect to the reference junction (cold) which is kept in cold water. This e.m.f. is transmitted to computer multiplexer terminals after suitable amplification.

Following points are considered for the choice of thermocouple.

1. Linearity in range of operation.
2. Higher e.m.f. per degree change in temperature, for higher accuracy in measurement.
3. Higher e.m.f. developed in the temperature range of operation. It reduces the complexities in signal transmission and amplifier design.

---

\*-A device that consists of junction of two dissimilar metallic conductors in which an e.m.f. is induced, when the conductors are maintained at different temperature.

The choice for thermocouple goes because of their small size, simple construction, ruggedness and linearity.

Base metal thermocouple (Iron Constantan - Type J) is chosen for the temperature measurement in the experimental set up. Amongst all types of thermocouple available, the above mentioned serves the purpose best.

### 3.12 COLD JUNCTION

The cold junction is kept in water (at room temperature). Since the set up has been fixed in an air-conditioned room, the temperature variations of the cold junction is quite low and the arrangement provide only moderate accuracy.

If this set up is at the place where ambient temperature variations, which effect temperature of reference junction are very frequent a temperature compensating network is required.

### 3.13 E.M.F. MEASUREMENT

The thermocouple output is suitably amplified by properly selecting the gain setting of amplifier and is transmitted to multiplexer (Relay type) and of computer. There the signal is converted to digital form using an analog to digital converter. The converted

digital values are read by computer into the accumulator.

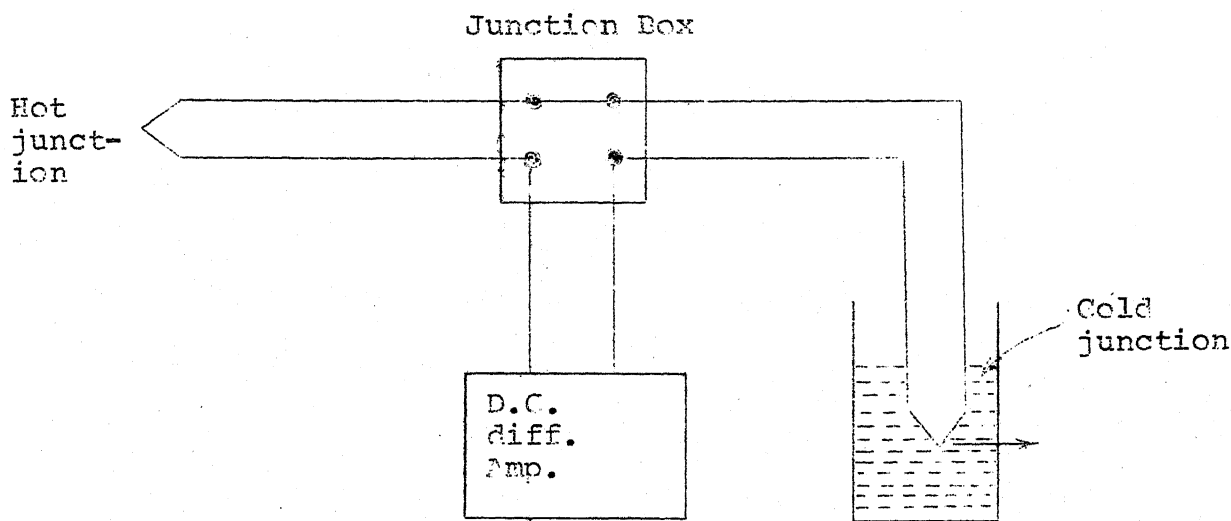


Figure 3.13: Temperature measurement using thermocouple

### 3.14 SIGNAL NOISE

In general the size of the process necessitates connexion of transducer by long cables to the input unit of computer. Quite often connecting cable is run close to the source of mains voltage, resulting in pickup on the leads. This pick-up voltage is added to the transducer output. For chemical processes, the frequency of information signal is much small compared to the pick-up frequency. Thus by designing a suitable low pass RC filter, between connecting cable and multiplexer, pick-up can be attenuated sufficiently.

In the experimental set-up, thermocouple is used to measure temperature. In the range  $0-100^{\circ}\text{C}$ , which develops a voltage of the order of  $3\text{m}\cdot\text{volts}$  while we working with the signal level of this order, electrical noise is a real problem. Appendix I presents a note on 'NOISE IN INSTRUMENT CIRCUIT'. A shielding procedure as shown in Figure 3.14 is used which reduces noise to a considerable limit.

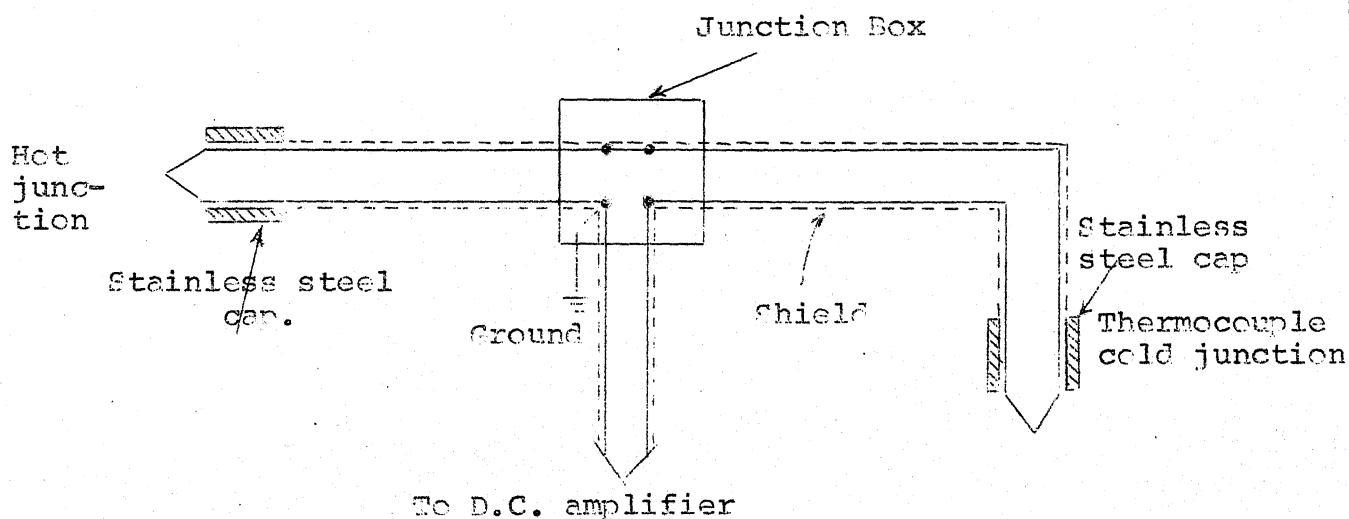


Fig. 3.1.4: Shielding procedure of thermocouple.



### 3.2 SIGNAL TRANSMISSION<sup>9</sup>

From the process, the type of signals available is usually d.c. in nature. These signals can be transmitted over moderately large distances. One thousand feet is considered nominal maximum. In any case source must have the capability to drive the total loop impedance, which is the sum of cable impedance and input impedance and input impedance of receiver (Only at low frequencies).

High level d.c. signals are transmitted directly on signal cables. The shielded cable is normally used to avoid noise pick up.

Following factors were considered for the transmission of high level signal.

- A. 1. Ratio of receiver input impedance to source output impedance is kept greater than 1000,  
The diff. amplifier output (output impedance 750  $\Omega$ ) is connected to relay multiplexer (input impedance 10 "  $\Omega$ ). So the above condition is satisfied.
2. Transmission Distance and Resulting Cable Impedance: The cable impedance is added to source to find the overall source impedance. In present experimental set-up, the input

signal cable is approximately 20 feet in length. So the cable impedance (less than 5  $\Omega$ ) is negligible compared to source (750  $\Omega$ ). Condition 1 is satisfied considering the overall source impedance.

B. The cable resistance and capacitance combines together to form a RC network, which acts like a filter. This filter should have a cut off frequency higher than the highest significant frequency in the signal input, so that the signals reach the computer without being seriously distorted and noise is reduced.

For the transmission of low level signals, following points are very helpful.

1. Transmission distance is kept as short as possible.
2. Signal cable shield is tied to the low side of the common point of signal source (the shield starts, right after the junction of thermocouple) and is maintained continuous upto computer multiplexer (Delay) terminals.
3. It is ensured that neither the cable shield nor the signal ground is grounded at more than one point.
4. All the power lines etc. are kept away from signal lines, so as to minimise the stray pick-up. If it becomes necessary to cross signal lines and power lines, they should be cut at right angle.

Typical specifications of cable recommended for the analog signals transmission to computer are the following.

1. Wire size should be #16 or # 18 A.W.G. to allow easy handling and termination without sacrificing strength or workability. This minimizes the lead resistance in the transmission line. Stranded wire with 19 strands is recommended.
2. The cable should be twisted pair, shielded and insulated. If multi pair cable is used, an overall shield and insulation is recommended in addition to pair shield and insulation.
3. Insulation should be rated to a minimum of 600 volts.
4. The temperature rating of cables must be consistent with maximum possible temperature conditions. (Recommended minimum specification is 75°C).

The signals of following types are generated in the process and in the computer. They are transmitted using different type of cables:

1. Thermocouple signal transmission to differential amplifier: Twisted pair, shield with braided copper.
2. Differential Amplifier to Computer: Two core, insulated and shielded.

### 3. Computer analog output to Power Control Unit:

Single core shielded and insulated.

### 3.3 INPUT INTERFACE:

As discussed earlier, thermocouples are used for the measurement of temperature. The magnitude of thermocouple voltages are very small (of the order microvolts / $^{\circ}\text{C}$ ). Since the input to computer must be of the order of volts (1-5 volts) high gain differential amplifier (gain 1000) was designed at input interface. The input impedance of amplifier must be high to avoid loading of thermocouple signals. (Ratio of receiver to source impedance must be of the order 100).

#### 3.3.1 D.C. Amplifier:

The following are the requirements of D.C. amplifier to amplify thermocouple and other low level signals.

1. High Input and low output impedance.
2. High common mode rejection.
3. High stability.
4. Good linearity in the range of operation.

#### 3.3.2 Design Considerations:

The thermocouple signals are in the range of 0 to 3.5 millivolts for the temperature range  $0^{\circ}\text{C}$  to  $100^{\circ}\text{C}$ . The floating low level signals obtained from thermocouple is amplified to the range specified by

Analog to Digital Converter (ADC). The output of the amplifier should be floating since the Relay Multiplexer in system requires the floating input.

A variable gain d.c. differential amplifier is designed, so that the same amplifier may be used for other transducers output to be coupled to computer input. The specifications decided for amplifier are:

1. Floating input and floating output.
2. Zero Offset arrangement.
3. Gain settings of  $\pm 1000$ ,  $\pm 500$ ,  $\pm 200$ ,  $\pm 100$ ,  $\pm 50$ ,  $\pm 20$  and  $\pm 10$  are available, so that all types of transducer output can be matched to computer input requirement.
4. Powered by external supplies  $+12$  and  $-12$  volts.

This amplifier can be used for one signal and in each low level signal line requires a separate unit.

#### DESIGN:

To achieve a differential gain of 1000 with high common mode rejection ratio, the use of operational amplifier is most appropriate. Since the output of available Op. Amp. is single ended, it is necessary to introduce a differential pair at output stage. The differential pair is used at the output stage, since the differential output can be obtained at the collectors of matched pair.

As the output stage can provide some gain, the gain requirements of the first stage can be reduced, and greater stability can be achieved in each stage. The output stage is designed for a fixed gain of 10. The various gain settings are obtained by changing the feed back resistance in steps. The Block Diagram is shown in Fig. 3.3.1.

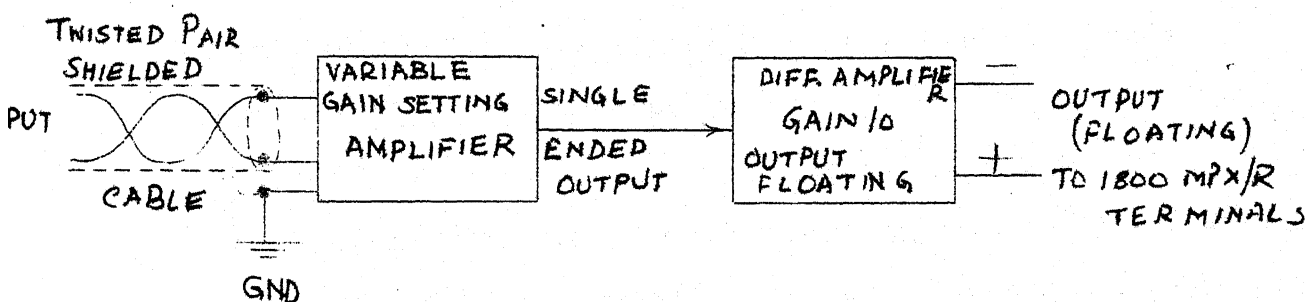


FIG. 3.3.1: BLOCK DIAGRAM of INPUT INTERFACE

### FIRST STAGE:

Operational amplifier <sup>13</sup>  $\mu A$  741 is used as shown in Fig. 3.3.  $\uparrow$  to accept differential input. Gain settings are changed by changing the feed back resistor instead of input resistor so as to maintain constant input impedance independent of gain settings. Identical resistor switching is provided between noninverting terminal of op-Amp and the ground, because of specified gain requirement. This is also essential to ensure uniform common mode rejection and low drift requirement. The offset compensation arrangement recommended by the manufactures is followed and can be adjusted by the variable resistance provided for the purpose.

The typical input bias current of  $\mu A$  741 is 200 nano amperes. The parallel combination of  $R_f$  and  $R_{in}$  must be such that the bias current flowing through this combination will not develop a voltage comparable to the signal which is 0.2 millivolts.

Therefore the parallel combination of feed back resistor ( $R_f$ ) and input resistor ( $R_{in}$ ) should be much less than  $1\text{ K } \Omega$ . Since for high gains parallel combinations of  $R_f$  and  $R_{in}$  is approximately equal to  $R_{in}$ . A practical value of  $R_{in}$  selected is  $200\text{ } \Omega$ . Therefore a  $220\text{ } \Omega$  resistor is used at the input side of operational amplifier.

The calculated values for required gain settings are tabulated below. The maximum closed loop gain required from this stage is 100.

| gain | $R_f = A \cdot R_{in}$ |
|------|------------------------|
| 100  | 22.0 K $\Omega$        |
| 50   | 11.0 K $\Omega$        |
| 20   | 4.4 K $\Omega$         |
| 10   | 2.2 K $\Omega$         |
| 5    | 1.1 K $\Omega$         |
| 2    | 440 $\Omega$           |
| 1    | 220 $\Omega$           |

#### DESIGN OF SECOND STAGE:

After first stage of amplification, the signal amplitude is of the order of 100 millivolts. The second stage is designed for differential output with a gain of 10. RCA 3028 I.C. op. amp. has been selected for this stage as it provides matched pair with a built in current source. Since the matched transistors are on the same chip, their thermal and electrical characteristics are identical. The differential output is obtained at the collectors of matched pair. Zero offset balance is provided at this stage by

Note: 1% Precision resistors are used for exact gain requirements.



controlling the injection of current at the base of one matched pair transistor. A variable resistance is connected between the collectors of matched pair transistors, to provide gain control.

The complete design has been worked out and the final values are shown in Fig. 3.3.2.

### 3.4 OUTPUT INTERFACE:<sup>14</sup>

The output interface is required to regulate the power dissipation across the heating element- thus regulating the heat input to the tank.

The analog output available from Digital to Analog Converter in the system -1800 is utilized as control signal. For the designed interface, the output of Analog Driver Amplifier is used as a control signal because of impedance matching problems. Analog Driver Amplifier provided in the system is a single ended, high gain differential amplifier, with a closed loop gain of two.

The Analog Driver Amplifier output is utilized as a reference signal to a unit which provide a gate (drive) voltage to the thyristor. Depending on the level of reference signal, the firing angle of thyristor is decided. The firing angle control regulates the flow of average current to the heater and hence the heat dissipation. The S.C.R. conduction angle can be varied from  $0^\circ$  to  $180^\circ$ .

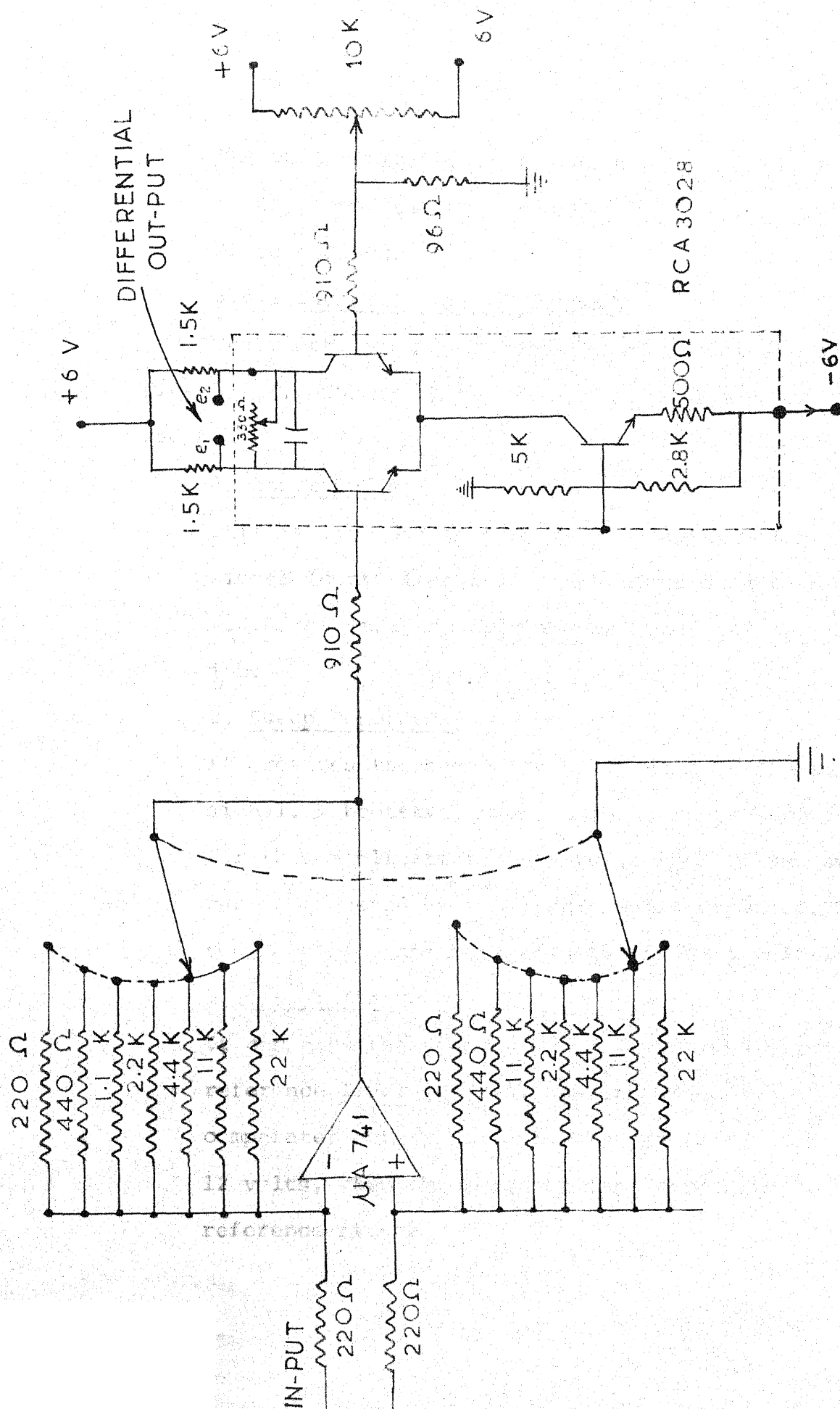


FIG. 3.3.2 VARIABLE GAIN DIFFERENTIAL AMPLIFIER

The unit comprises of two parts.

1. Thyristor Firing Circuit

2. Load Circuit.

3.4.1 Thyristor Firing Circuit:<sup>22</sup>

The block diagram for the firing circuit is shown in Fig. 3.4.1. The function of different blocks are described below:

1. Input Buffer:

This is provided to prevent the loading of reference signal (control signal) which comes from computer A.D.A. An emitter follower has been used for this job.

2. Sweep Generator:

It provides the sweep for half cycle of the a.c. signal. A bootstrap sweep generator has been designed for this application. Maximum voltage of the sweep can be adjusted by a potentiometer provided. The sweep voltage has been adjusted to be 5 volts.

3. Comparator:

It compares the sweep voltage level (0-5 v) with reference level (0-5 v), obtained from A.D.A. The comparator output level is changed from 0 volts to 12 volts, when the sweep voltage becomes more than reference signal.

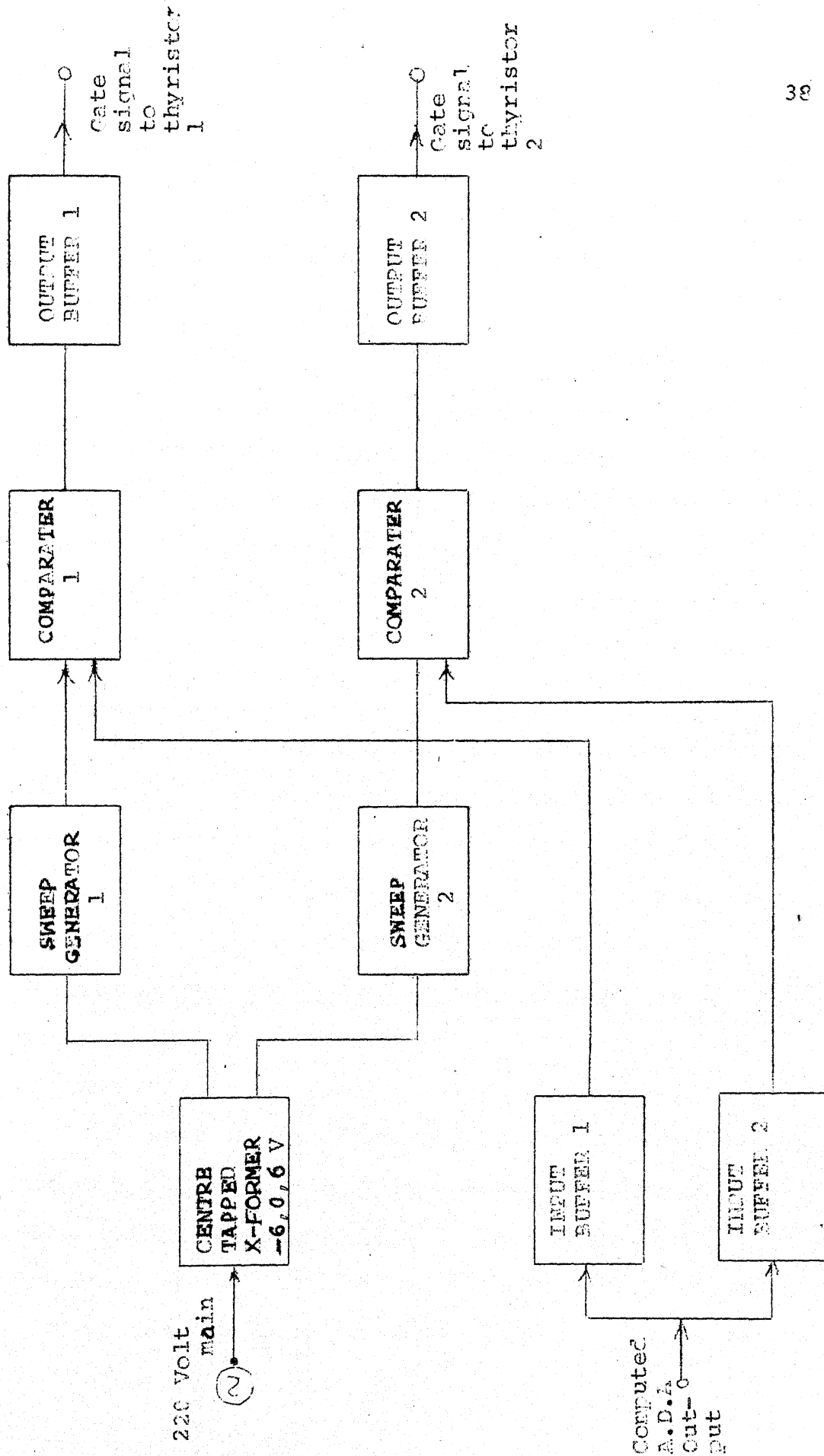


FIG. 3.4. 1- firing Circuit.

#### 4. Output Buffer:

It is required to reduce the comparater output level from 12 volts to 2 volts, as required by the specifications of S.C.R. gate voltage.

The one channel which comprises of all these blocks, gives firing pulse which controls the current flow through thyristor for half cycle only. To achieve control for complete cycle, one more channel 'channel 2' is used which operates in  $180^\circ$  phase difference.

The operation of this circuit is represented in Fig. 3.4.2.

#### LOAD CIRCUIT:

This is the final control circuit, which regulates the flow of current through load. The load is connected as shown in Fig. 3.4.3. The diodes are connected to provide for the termination of other end of load. The transformer is used to avoid the grounding of S.C.R. The thyristors have been shunted by a resistance, capacitance combination to prevent the damage of S.C.R. against voltage surge.

In our case load is purely resistive, so voltage and current are naturally in phase, resulting in some what simpler method of control. Because of phase controlled mode of operation various harmonics are generated depending on the conduction angle. Care is taken

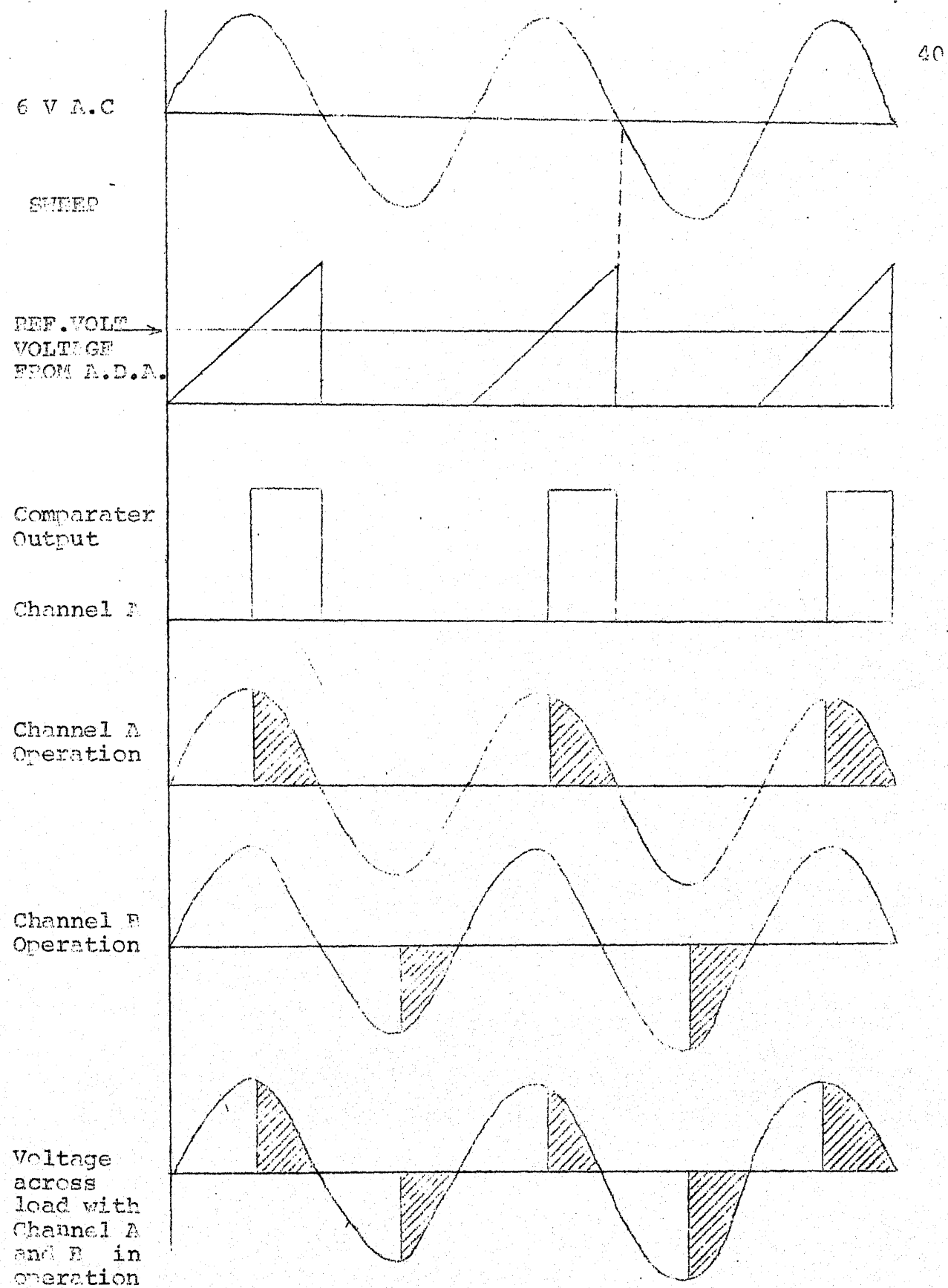


FIG. 3.4.2: Operation of Output Interface.

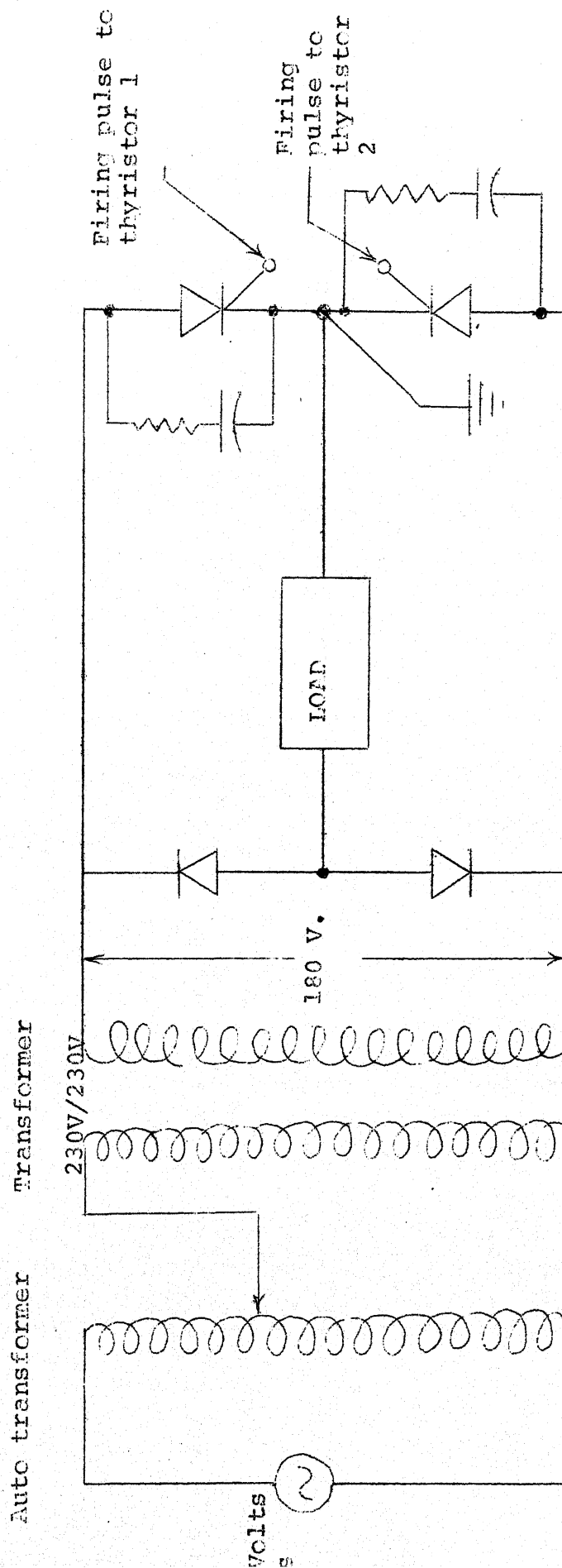


FIG. 3.4.3: LOAD CIRCUIT.

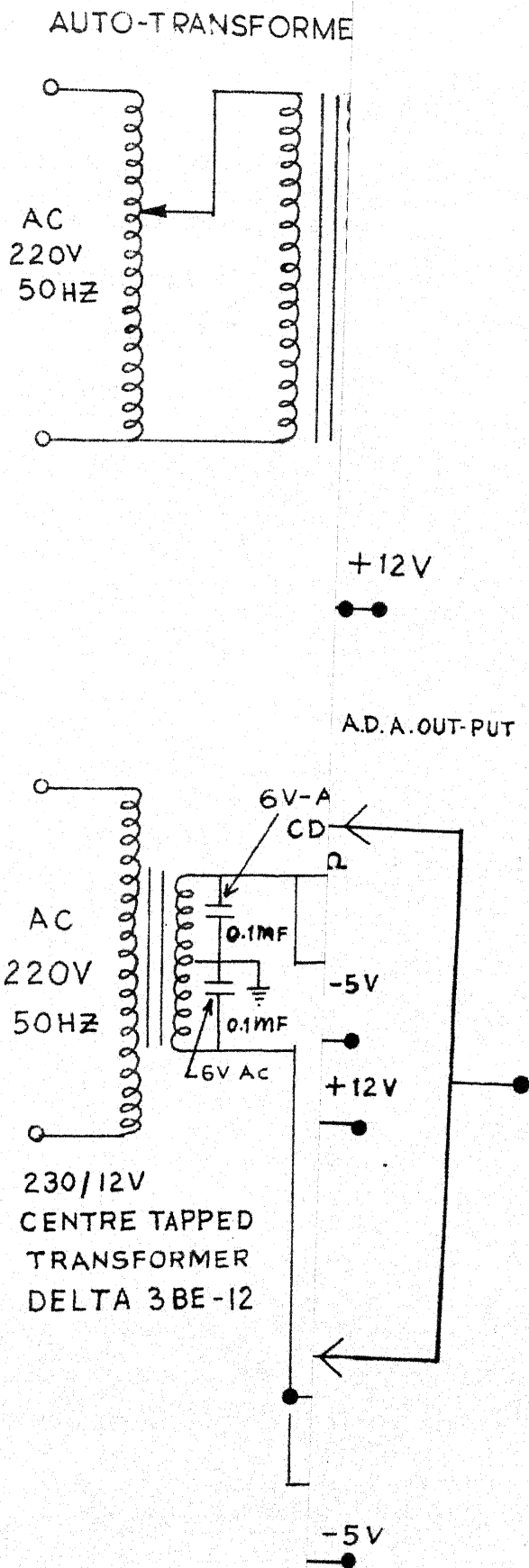
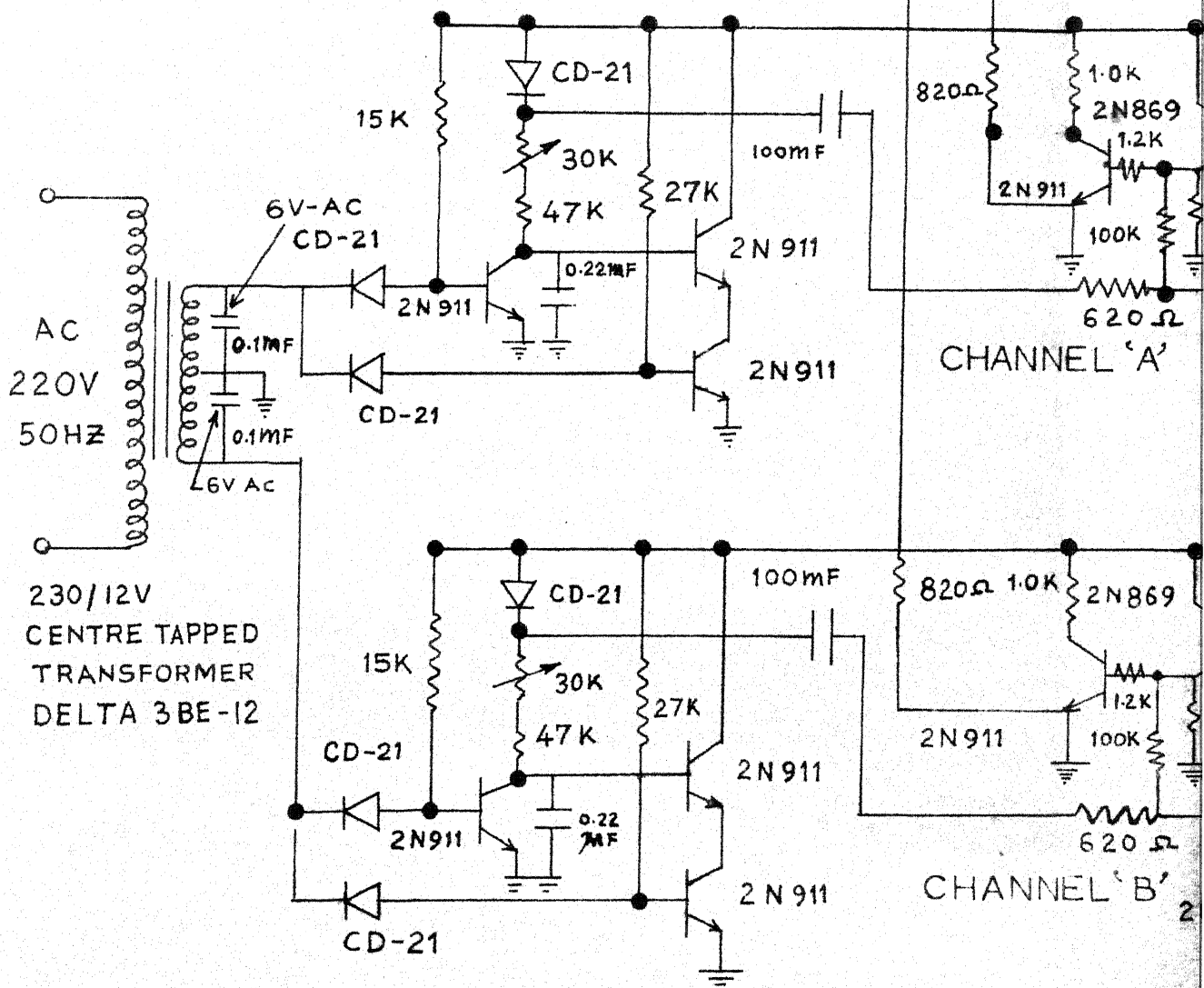
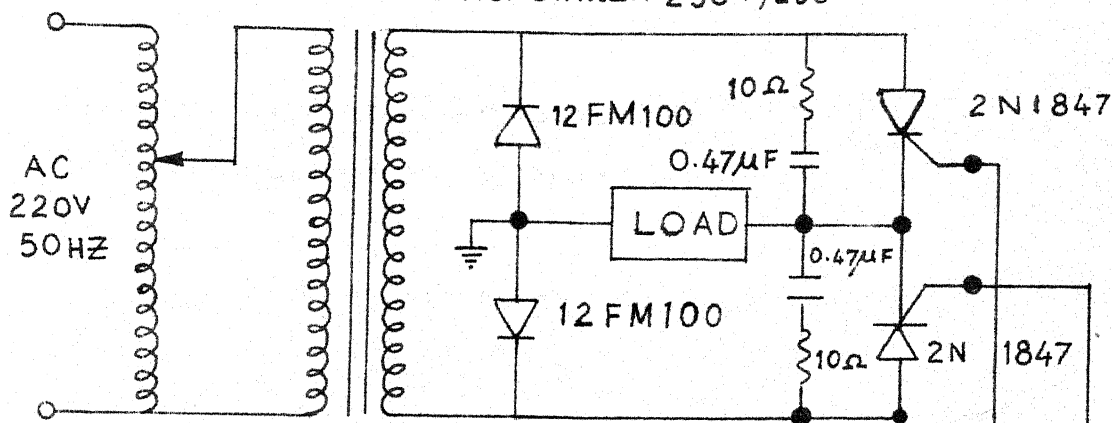
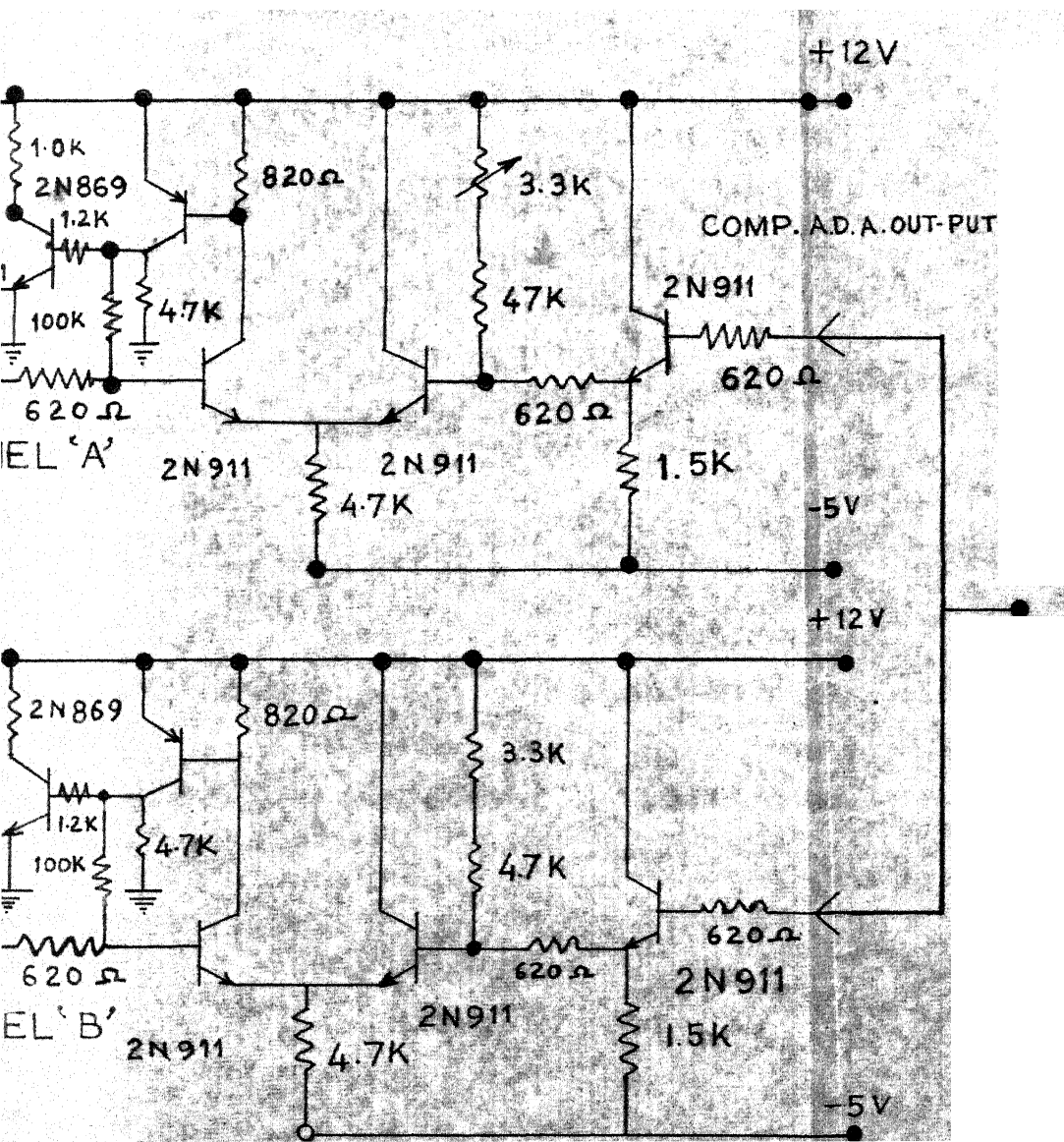


FIG. 3.4.4 POWER



# AUTO-TRANSFORMER TRANSFORMER 230V/230V





about the shielding of signal lines in the vicinity of this equipment, because of the power frequency harmonic generation.

Fig. 3.4.4 represents the complete design of output interface.

## CHAPTER 4

### SOFTWARE

Some aspects of the software required is described in section 2.4. The complete scheme is described below.

When a switch is closed at the process terminals, a contact closure is recognized at Process Interrupt Status Word (PISW) bit 03. The PISW bit 03 is wired at Interrupt Level Status Word (ILSW) bit 00. The programs for reading analog voltages and control signal generation etc. can not be executed at level zero, because all the process I/O devices and disk are attached at higher interrupt level. The highest interrupt level at which the program can be executed is at level 6 (Appendix 3). This program is executed at basic level. The process programs are executed at higher priority than non process programs.

On recognition of an interrupt at PISW bit 3, the arrangement to queue a core-load 'PMFSS' at basic level, is obtained by including a sub-routine 'INT1' in Executive. The cycling of control program is achieved by including 'SCAN' routines in Executive. Four SCAN routines are included in the system executive. The included routines SCAN, SCAN1, SCAN2 and SCAN3, provides for the cycling of another coreload 'ANLOG' at different intervals of time. . These routines are written utilizing the COUNT routines facility provided by system

Subroutine Library. The routines also test, the number of times 'ANLOG' has been executed and terminate their execution after 120 times. The routines INT1 and SCAN's are included in the system at system generation time by a \* INCLD card. The various SCAN routines are included in system to see the effect of sampling period on control.

When INT1 has been executed, the interrupt level 00 is reset and program 'PMESS' is queued. 'PMESS' is a queueable coreload and is stored on disk mounted as drive zero. The Variable Core (V Core) is saved on the disk in Nonprocess Save Area before 'PMESS' is loaded on the memory.

The coreload 'PMESS' gives message to the operator on typewriter 1 and asks some information about the process. The operator feeds the desired information to computer through keyboard. After the information is received, the program starts COUNT routine which inturn queues coreload ANLOG at specified intervals.

Coreload 'ANLOG' consists of a main program and three subroutines as given below:

|            |   |
|------------|---|
| 1. 'ANLOG  | Main program  |
| 2. 'READ'  | Read MPX/R point 1  |
| 3. 'CNTRL' | Control program   |
| 4. 'DISPL' | Control output is converted<br>to analog form and is<br>transmitted to process. |

Fig. 4.1 explains about the various coreloads and sub-routines. The program flow is also represented in this figure. Flow chart represented in Fig. 4.2 represents the interrupt servicing procedure.

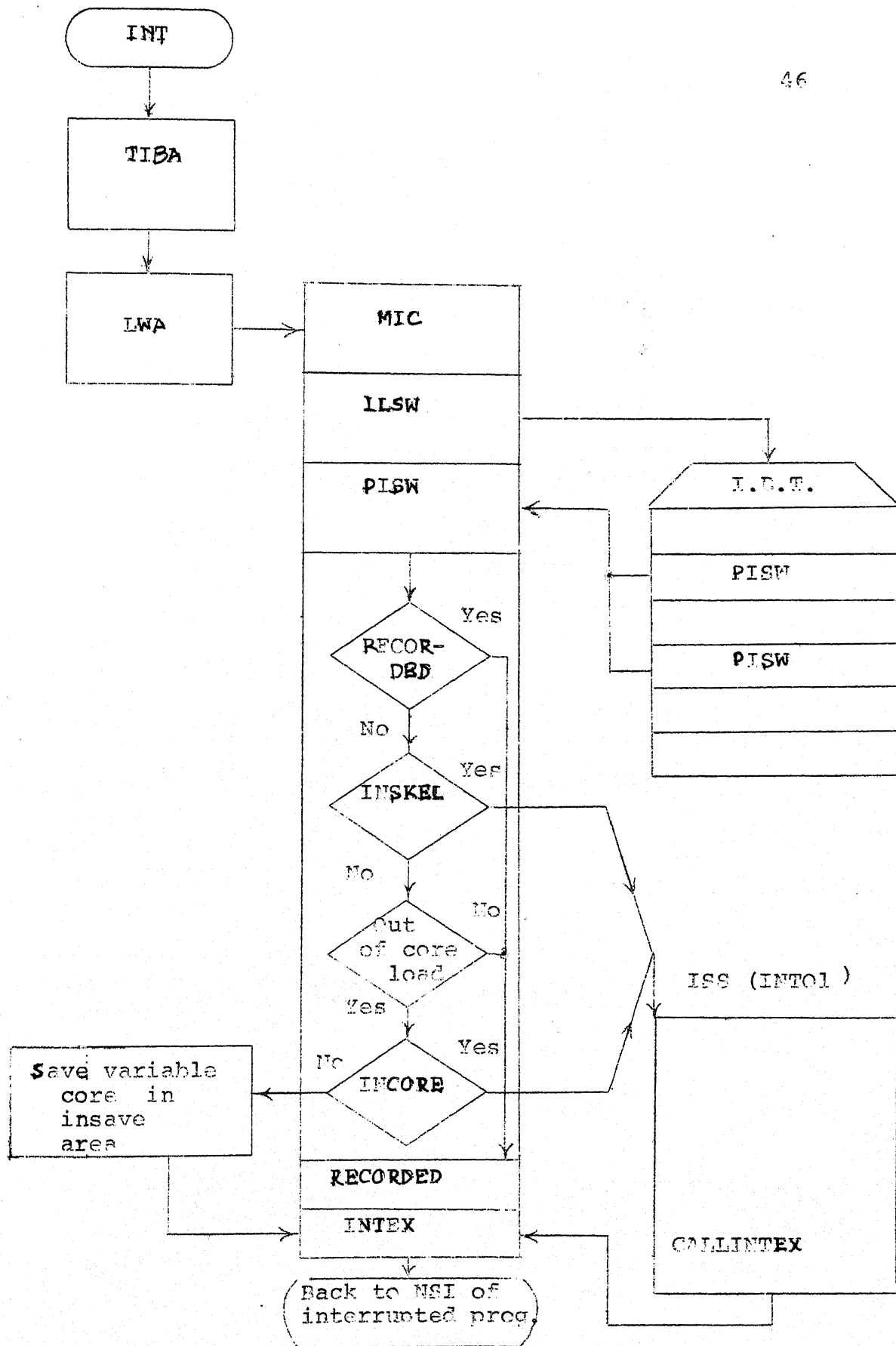
#### 4.1 BRIEF DISCUSSION ABOUT CORELOADS & SUBROUTINES:

The functions of various coreloads and subroutines are discussed in brief below. The routines used in programs are classified below:

1. Routines included in Executive.
2. Routines required for main program ANLOG.

##### 4.1.1 Executive Routines:

- A. 'INT01' Routine: This routine is in executive interrupt servicing routine. This services the interrupt at PISW bit 3. It queues a coreload 'PMESS'.
- B. Routine 'SCAN': It is a 'COUNT' routine included in executive. The number allotted to this count



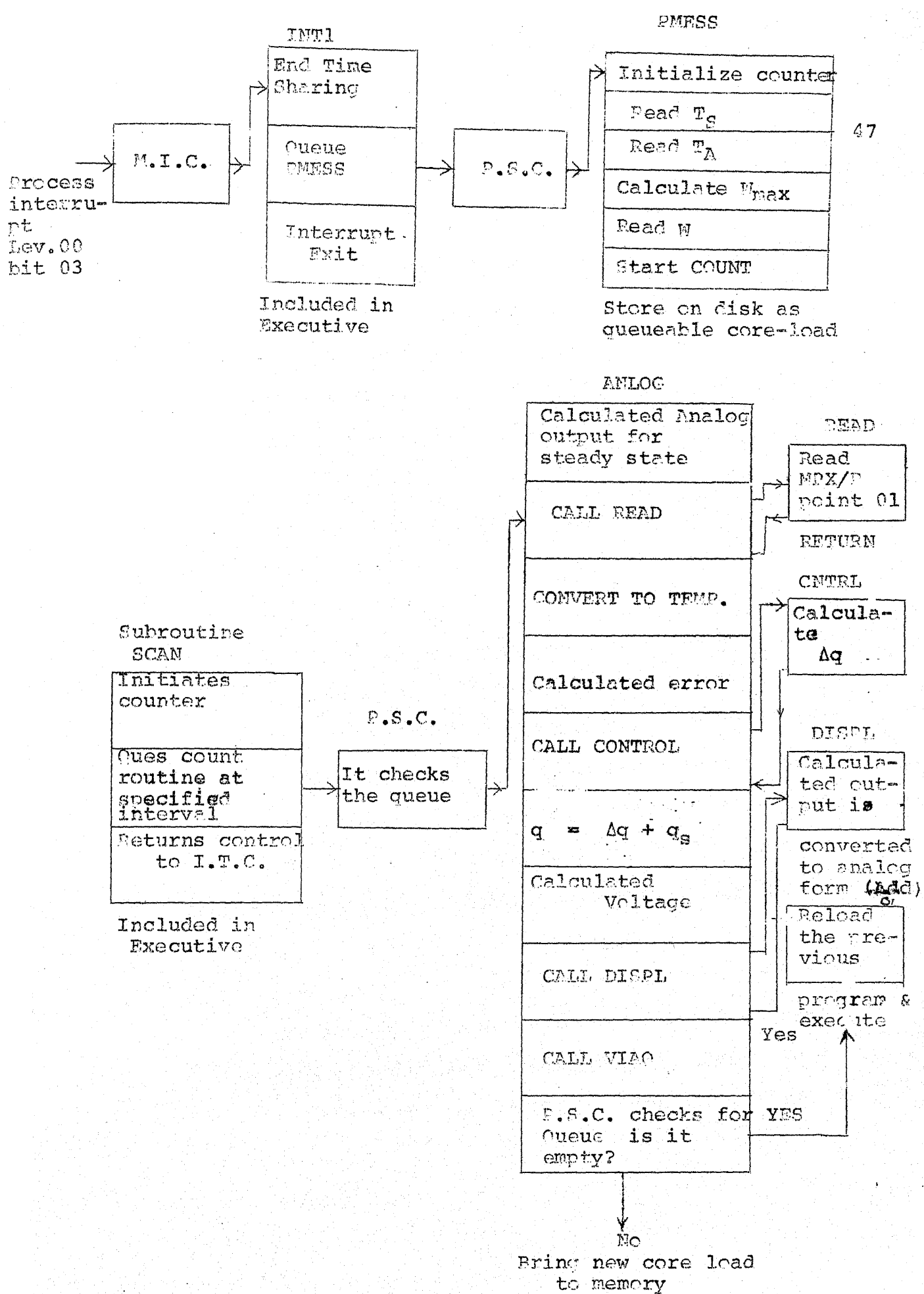


FIG. 4.1 : VARIOUS CORE LOADS IN PROGRAM.



routine is 5. It ends the time sharing and queues coreload 'ANLOG' 120 times. It provides for the periodic Execution of 'ANLOG' after every 60 seconds.

- C. Routine SCAN1. It is a 'COUNT' routine included in Executive. The number allotted to this count routine is 2. It ends the time sharing and queues coreload 'ANLOG' 120 times, after every 10 seconds.
- D. Routine SCAN2. It is a 'COUNT' routine included in Executive. The number allotted to this count routine is 3. It ends the time sharing and queues coreload 'ANLOG' 120 times after every 30 seconds.
- E. Routine SCAN3. It is a 'COUNT' routine included in Executive. The number allotted to this count routine is 4. It ends the time sharing and queues coreload 'ANLOG' 120 times after every 2 minutes.

#### 4.1.2 Main Program & Its Routines:

- A. Main Program 'ANLOG': Main program 'ANLOG' finds the steady state power required for the given flow, setpoint temperature, ambient temperature and reads voltage at MPX/R point 01 on first iteration. At the second iteration it reads analog voltage at MPX/R point 01 converts it

to corresponding temperature. This conversion is achieved by the thermocouple calibration curve. After reading the tank temperature it finds the error (error = Set Point temperature read) and adjusts control output voltage accordingly.

- B. Routine 'READ': It reads multiplexer point 01 and stores the value in location 'AREA'.
- C. Routine 'CNTRL': It finds control output as a function of 'error', determined by main program 'ANLOG'.
- D. DISPL: The output value calculated by routine 'CNTRL' is converted to analog form and is brought at Digital to Analog Converter output terminal (Address 01).

#### 4.2 CORE LOADS:

- A. Core Load 'PMESS': It is a main line queueable coreload reads, set point temperature, ambient temperature and finds out the value of the flow. It instructs the operator to adjust the flow rate less than the specified value. The adjusted flow rate is informed to Jomputer by the operator. Set point temperature, ambient temperature and flow rate adjusted are stored in 'INSKEL COMMON' area.

B. Core Load 'ANLOG': It is described in Section 4.1.2.

#### 4.3 OFF LINE PROGRAMS DEVELOPED:

Two off line programs were developed. The function of these programs are discussed briefly here.

##### 4.3.1 Polynomial Fitting Routines:

It fits the best polynomial for the set of data obtained from process. This program has been used for following calibrations.

- a. Thermocouple calibration
- b. Input Rotameter Calibration
- c. Output Rotameter Calibration
- d. Power Control Unit Calibration.

##### 4.3.2 'PLOT' Routine:

It is a XY plot program, which has been used for following applications:

- 1. 'Thermocouple Calibration'
- 2. Temperature Vs. Time plot for controlled and uncontrolled operation.

---

Note: Flow chart (Appendix E) explains in detail the sequence of operations of various core loads.

## CHAPTER 5

## RESULTS and DISCUSSIONS

The designed input and output interfaces were used to connect the process with the computer. The designed interfaces were calibrated and calibration curve equations were obtained using least square fit. The software package has been written for reading the temperature of tank and control of temperature, so as to minimize the errors arising due to fluctuations in load or change in set point. So as to prove the effectiveness of the interfaces and control program, an experiment was conducted as an example in which the response of digital control system to a step. Change in disturbance signal is observed. The observed results show that the controlled variable settles down around the set point. The results show small fluctuations in controlled variable, which might be due to sustained variations in load variables like flow rate or change in mains voltage supplied to heater. However control variable does settle down to steady state value within 5 minutes of the disturbance. The results are shown in Figure 5.0.

The following factors contribute to the errors introduced in the system.

# 1. Error associated with thermocouple measurement device:

The present experimental set up does not include any arrangement to compensate for the variation of reference junction temperature. These variations alter the calibration curve coefficients, which results in incorrect recording of temperature. The differential amplifier introduced in input signal line may also introduce some drift, which may alter the output voltage from actual value and hence introduce some error in recording of temperature. Some stray pick-up in signal line may also alter the voltage at multiplexer terminals. A suitable designed RC filter will attenuate the pick up to considerable standard.

## 2. Noise introduced in system because of sampling.

Because of sampling at relay multiplexer terminals some noise is introduced in the measured signal voltage. A digital filter introduced in the control loop will considerably improve the response.

### 5.1 Suggestions for further improvement and work

1. There should be some method to indicate to computer and operator, if the thermocouple junction measuring the temperature breaks.

2. Compensatory networks which takes into account of variation of reference junction temperature should be included in measurement circuit.

3. Some basic assumptions made during the development of control model like constant head of water in stirred tank and flow rates, are not true in the present physical system.

The pumps used in the system for maintaining constant flow rates, results in sustained oscillations in the system. This can be improved by the gravity flow scheme.

4. The other heat losses in the system have not been considered in the model, as such the system has to be insulated thoroughly to minimize radiation losses.

5. Optimum sampling period should be determined so as to avoid high computer cost and maintaining desired accuracy.

## APPENDIX I

### NOISE IN INSTRUMENT CIRCUIT AND ITS REDUCTION METHODS<sup>18,19</sup>

Different type noise which influence the process signal are classified below and their reduction procedure is discussed.

#### I.1 STATIC NOISE:

Electrical voltages around the process get capacitively coupled to the wires in instrument circuit. Because of this coupling an a.c. noise signal is superimposed on d.c. process signal and is transmitted across the wires in instrument circuit. Low level signals are greatly affected by this noise.

Coupling between external sources and instrument circuit is broken by means of a static shield, which is properly grounded.

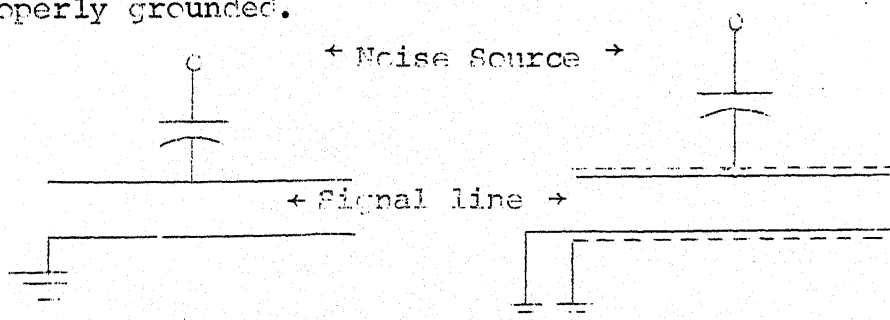


Fig. 1: Coupling shown

Fig. 2: Coupling broken by shield.

#### I.2 MAGNETIC NOISE:

This noise is generated due to the stray magnetic fields present. Stray magnetic fields are produced around a conductor carrying current.

As a result, all power lines, motors- transformers etc; radiate magnetic fields of erratic and varying strengths. Anytime magnetic fields are coupled to thermocouple loop, noise current flowing through transducer loop produces a noise voltage. The noise voltage is in turn superimposed on voltage being transmitted by the pair of wires.

Following are the two methods used to avoid magnetic noise.

1. Twisting the wires in transducer loop: In this case wire pair forms a series of loops in signal circuit. This way adjacent loops cancel the effect of induced magnetic field.
2. Shielding the signal wires: It cancels any magnetic field, through the production of eddy currents, within the shield material.

#### COMMON MODE NOISE:

Varying ground potentials at different points in the experimental set-up cause common mode noise. If both the thermocouple and computer terminals are grounded, varying ground potentials cause circulating current. The presence of common mode signal is not a source of major error. But in practice "Common Mode Voltage" is converted to a differential signal which adds to the true signal. The common/mode noise is particularly



trouble some in thermocouple circuit. The process of converting common mode voltage to differential voltage in a system is very complex due to distributed leakages and capacitances in actual system.

#### AVOIDING COMMON MODE NOISE:

The source of common mode noise is avoided by using differential input, so that neither input terminal is grounded. Even with this arrangement, common mode noise can be caused by ground metal objects close to the wires which cause charging current to flow through capacitive coupling. In thermocouple circuit two instrument wires have different resistances, so the resulting voltage drop appears as common mode noise. This cause of C.M. noise is eliminated by placing a shield around the wires and grounding it at thermocouple, so that wires and shield are at the same potential. If shield is grounded away from thermocouple, differing ground potential will cause common mode noise. Common mode noise reducing arrangement is shown in Fig. (c).

In thermocouple circuit, all the above mentioned noise is avoided by taking thermocouple wires small in length, and connecting it to twisted pair shielded wire. The shield is grounded at thermocouple end. Before feeding the thermocouple signals to computer,

amplification is needed. So a differential amplifier with high/common mode rejection capability is to be designed.

The relay multiplexer provided in system 1800 helps a great deal in improving common mode rejection. Common mode source is being disconnected for the period during which particular input is not being measured.

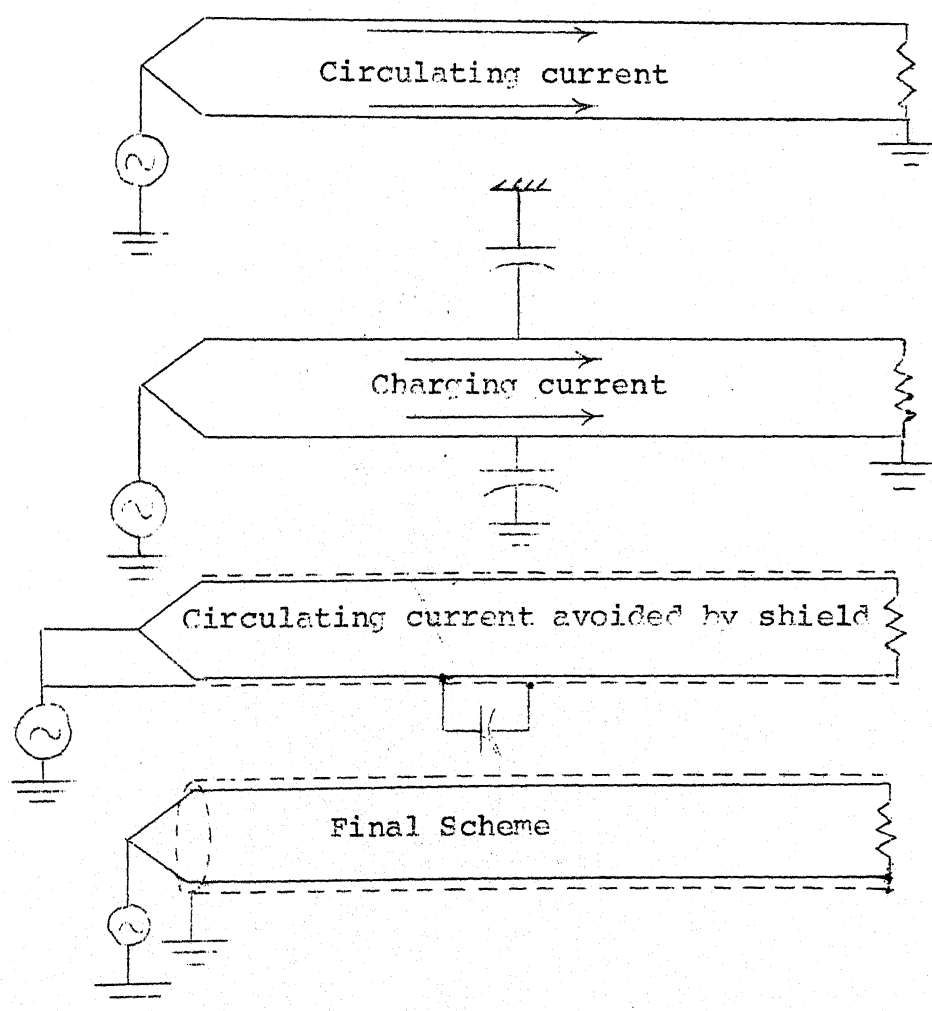


Fig. C: Common mode noise reduction.

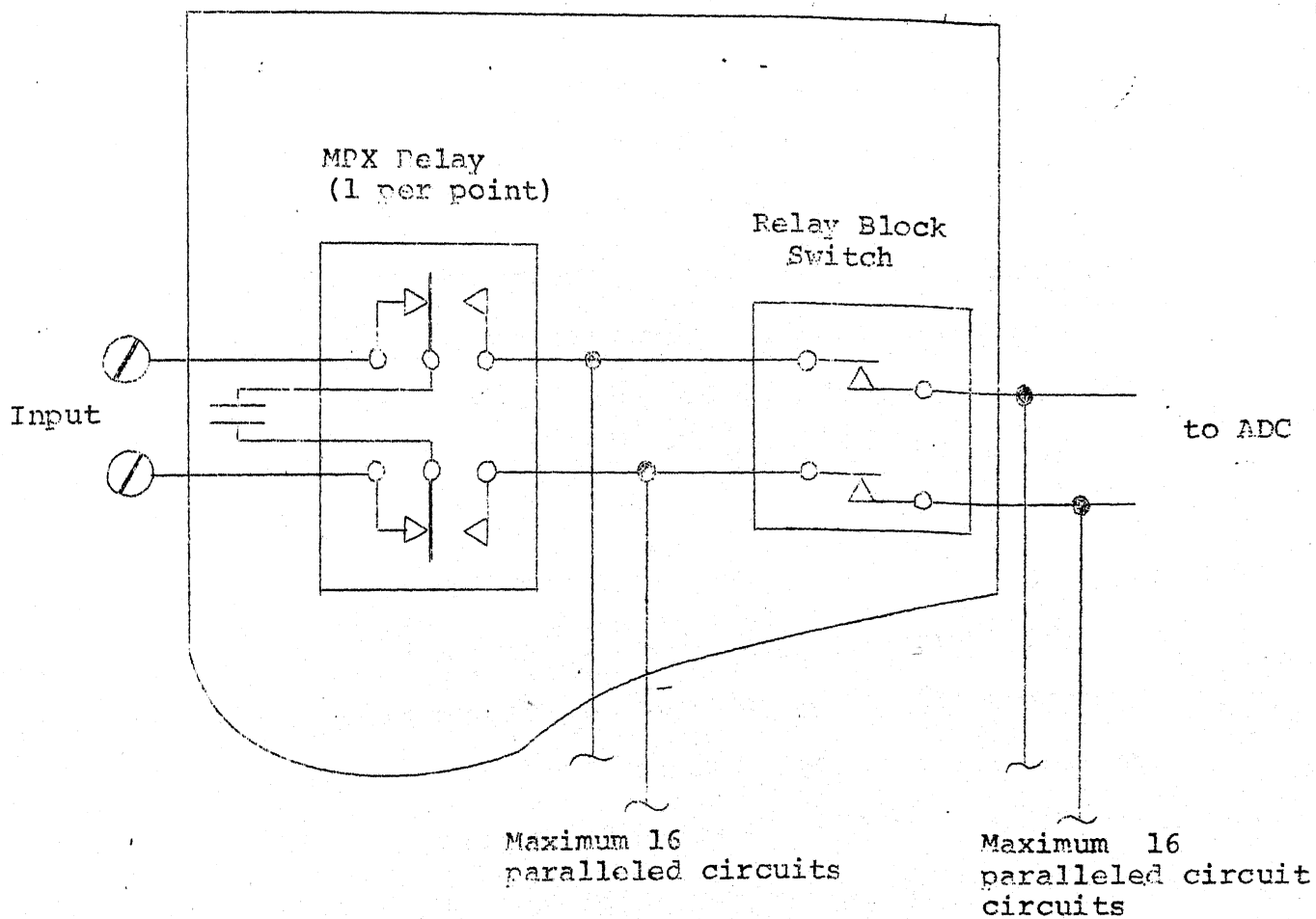


Fig. d: Relay Multiplexer Signal Paths.

## APPENDIX II

### THERMOCOUPLE CALIBRATION <sup>10</sup>

Thermocouple calibration is required to determine the temperature of the hot junction. Since the thermocouple develops a voltage depending on the temperature difference of hot and cold junction. If a relationship is known between difference in temperature between junction (when reference voltage is kept constant) and voltage developed, we can directly find the temperature of hot junction.

#### PROCEDURE:

The temperature in the bath is maintained constant and the corresponding voltage developed from thermocouple is measured. The number of readings are taken for one steady state value and their mean is found out. Approximately five such readings are taken and a curve is fitted for the minimum error.

The equation of the fitted curve is given in attached sheet. A plot of temperature Vs. signal voltage is shown in Fig. II-1.

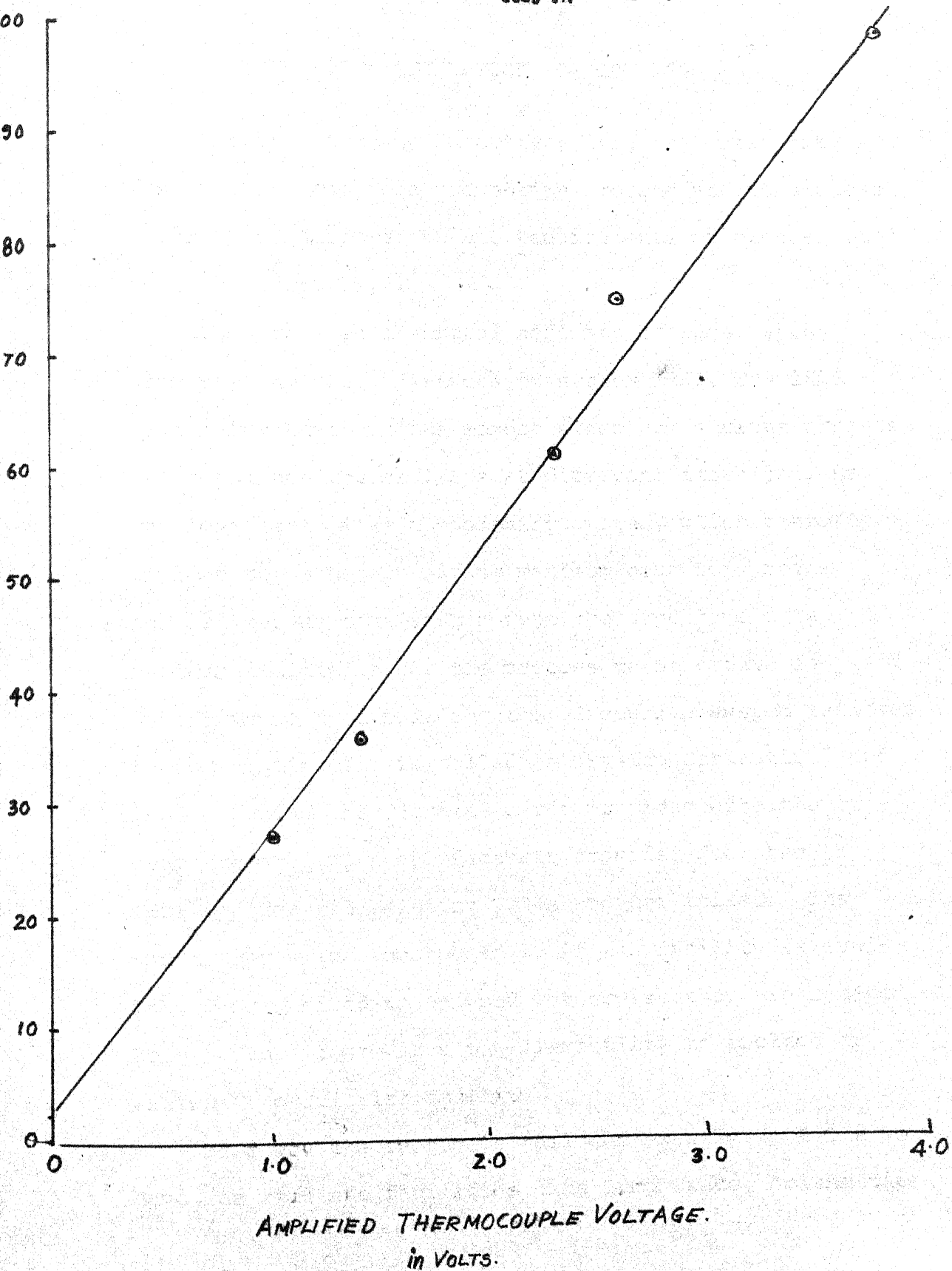
#### SOURCES OF ERROR:

1. The accuracy of thermocouple. It varies from  $0.5^{\circ}\text{C}$  to  $2^{\circ}\text{C}$ .
2. Heat distribution between the medium, where the temperature is being measured.

3. Variation of Cold junction temperature.
4. The accuracy of measurement is largely dependent on the installation of thermocouple.
5. The current drawn from thermocouple also affects the voltage developed.

# CALIBRATION OF INPUT INTERFACE.

$T_{\text{COLD JN}} = 22^{\circ}\text{C}.$



### APPENDIX III

#### TSX-SYSTEM GENERATION FOR IBM 1800 <sup>1,20</sup>

The time sharing Executive, i.e. the operating system which controls the entire process and nonprocess programs is tailored to the requirements of process that is to be controlled.

IBM provides a general software package, which supports the total features of system 1800. The 1800 system may have various memory sizes and various process I/O's and nonprocess I/O's at different installations. The idea is to make a operating system, which takes up minimum core thereby giving maximum core for process and nonprocess coreloads and at the same time have maximum facilities for the process to be controlled.

This part of building the Executive system tailored to our requirement is called as "System Generation" and is done using the 'Equate' cards provided with the program package. The manufacturer provided deck has the facility for all existing I/O's and utilities. The Equate cards are equated to 1, if the facility is available and desired to be used, otherwise they are equated to 0. Thus it provides the flexibility to include or exclude a particular facility.

This way the system is tailored exactly to I/O's we have, as well the facilities like Dump Trace, Arithmetic

trace that we need. The SYSTEM GENERATION also tailors the disk areas to our needs; i.e. we would have more temporary working storage or more fixed core image area. The other aspects of SYSGEN is that it assigns Logical Unit Numbers (LUN) to various I/O devices, to be called in FORTRAN programs. It also includes the user's subroutine and loads library decks in the Executive for fast response.

A complete listing of EQUATE CARDS and their value is attached, (Appendix III-a). With the current Equate Cards memory requirement is calculated. It takes approximately 7 K words of the memory leaving 9 K words for Variable Core.

#### PROCEDURE:

The step by step procedure for system generation is described in IBM 1800, TSX operating procedures.



// JCB  
 // ASM TASK  
 \*OVERFLOW SECTORS 32  
 \*PUNCH

|            |      |           |           |          |               |                  |
|------------|------|-----------|-----------|----------|---------------|------------------|
| HDNG       | USER | EQUATE    | CARDS     | GROUP    | 1             |                  |
| ABS        |      |           |           |          |               |                  |
| *****      | USER | GROUP     | 1         | EQUATE   | CARDS         | FOLLOW ***       |
| CCRSZ EQU  | 16   | OBJECT    | CORE      | SIZE     | * 8,16,32     | *                |
| COMSZ EQU  | 51   | CBJECT    | INSKEL    | COMMON   | MAX WD        | SIZ              |
| CCRSPE EQU | 4    | CORE      | SPEED,2   | IF 2US,4 | IF 4US        | M9               |
| DORC1 EQU  | 1    | 0         | IF ONE    | DISK     | DR,ELSE       | 1                |
| CCRC2 EQU  | 0    | 0         | IF TWO    | DISK     | DR,ELSE       | 1                |
| PRIL1 EQU  | 1    | DISK      | DR        | INTER.   | LEVEL *       | 0/23 *           |
| PRIL2 EQU  |      | DISK      | DR        | 2 INTER. | LEVEL *       | 0/23 *           |
| PRIL1 EQU  | 1    | DISK      | DR        | 1 INTER. | LEVEL *       | 0/23 *           |
| TORG EQU   | 1    | 0         | IF SYSTEM | HAS      | NO 1816,ELSE  | 1                |
| TORG1 EQU  | 0    | 0         | IF 1      | 1053     | OR 1816       | ON GP1,ELSE 1    |
| TORG2 EQU  | 1    | 0         | IF 2      | 1053     | OR 1816       | ON GP1,ELSE 1    |
| TORG3 EQU  | 1    | 0         | IF 3      | 1053     | OR 1816       | ON GP1,ELSE 1    |
| TORG4 EQU  | 1    | 0         | IF NO     | 1816     | ON GP1,ELSE   | 1                |
| TORG5 EQU  | 1    | 0         | IF NO     | 1053     | CR 1816       | PRS ON GP2,      |
| TORG6 EQU  | 0    | 0         | IF 1      | 1053     | OR 1816       | ON GP2,ELSE 1    |
| TORG7 EQU  | 1    | 0         | IF 2      | 1053     | OR 1816       | ON GP2,ELSE 1    |
| TORG8 EQU  | 1    | 0         | IF 3      | 1053     | OR 1816       | ON GP2,ELSE 1    |
| TORG9 EQU  | 1    | 0         | IF NO     | 1816     | ON GP2,ELSE   | 1                |
| TORG10 EQU | 1    | 0         | IF SYSTEM | HAS      | NO 1053       | OR 1816          |
| BLAST EQU  | 0    | 1         | IF BLAST  | CMD      | FOR 1053,ELSE | 0 M9             |
| TYPL1 EQU  | 3    | 1053/1816 | GP1       | INTER.   | LEVEL         |                  |
| TYPL2 EQU  | 3    | 1053/1816 | GP2       | INTER.   | LEVEL         |                  |
| INTK1 EQU  | 6    | USER      | KB        | REQ      | RTN INT       | LVL, KB1 3.7     |
| INTK2 EQU  | 8    | USER      | KB        | REQ      | RTN INT       | LVL, KB2 3.7     |
| NOBLF EQU  | 1    | 0         | IF NO     | DISK     | MSG           | BUFFERING,ELSE 1 |
| NOCYL EQU  | 4    | NO.       | OF        | CYLS     | FOR           | MSG              |
| NUMBE EQU  | 8    | NO.       | OF        | NON-PRCC | MSG           | BUFF SECTORS     |
| BZ1 EQU    | 60   | MSG       | UNIT      | SIZE,    | 1053-1,       | GP1              |
| BZ2 EQU    | 0    | MSG       | UNIT      | SIZE,    | 1053-2,       | GP1              |
| BZ3 EQU    | 0    | MSG       | UNIT      | SIZE,    | 1053-3,       | GP1              |
| BZ4 EQU    | 0    | MSG       | UNIT      | SIZE,    | 1053-4,       | GP1              |
| BZ5 EQU    | 60   | MSG       | UNIT      | SIZE,    | 1053-1,       | GP2              |
| BZ6 EQU    | 0    | MSG       | UNIT      | SIZE,    | 1053-2,       | GP2              |
| BZ7 EQU    | 0    | MSG       | UNIT      | SIZE,    | 1053-3,       | GP2              |
| BZ8 EQU    | 0    | MSG       | UNIT      | SIZE,    | 1053-4,       | GP2              |
| PORG EQU   | 0    | 0         | IF NO     | 1443,    | ELSE          | 1                |
|            |      |           |           |          |               | MODJ1            |

TSK00010  
 TSK00020  
 TSK00050  
 TSK00060  
 TSK00065  
 TSK00070  
 TSK00080  
 TSK00090  
 TSK00100  
 TSK00105  
 TSK00110  
 TSK00120  
 TSK00130  
 TSK00150  
 TSK00140  
 TSK00160  
 TSK00170  
 TSK00180  
 TSK00190  
 TSK00200  
 TSK00210  
 TSK00220  
 TSK00230  
 TSK00240  
 TSK00250  
 TSK00260  
 TSK00265  
 TSK00270  
 TSK00280  
 TSK00290  
 TSK00295  
 TSK00300  
 TSK00310  
 TSK00320  
 TSK00330  
 TSK00340  
 TSK00350  
 TSK00360  
 TSK00370  
 TSK00380  
 TSK00390  
 TSK00400  
 TSK00405

|          |    |                                   |          |
|----------|----|-----------------------------------|----------|
| TSK00420 | 0  | IF 1053,1 IF 1443                 | TSK00430 |
| TSK00430 | 1  | SYSTEM PR.,0 IF 1053,1 IF 1443    | TSK00440 |
| TSK00440 | 0  | WHICH OF 3 1053/1816 +S SY/LST P  | TSK00450 |
| TSK00450 | 0  | IF EAC PR IS 1053,1 IF 1443       | TSK00460 |
| TSK00460 | 1  | EAC TYPWR COMBINATIONS *1 TO 15 * | TSK00470 |
| TSK00470 | 0  | IF EAC TYP CN GPL,ELSE 1          | TSK00480 |
| TSK00480 | 0  | 1 CARD I/O IN SKELETON 0 ELSE     | TSK00490 |
| TSK00490 | 0  | IF 1 1442, ELSE 1                 | TSK00500 |
| TSK00500 | 0  | IF NO OVLP AN.IN.BASIC,ELSE 1.    | TSK00510 |
| TSK00510 | 0  | IF NC CVLP AN.IN.EXP.,ELSE 1.     | TSK00520 |
| TSK00520 | 0  | EXITS TO EAC.1,LCCPS UNTIL RDY.   | TSK00530 |
| TSK00530 | 7  | LEVEL OF USER CCNS.INT.RTN.       | TSK00540 |
| TSK00540 | 12 | TOTAL NO.LEVELS AT FINAL TSX TIME | TSK00550 |
| TSK00550 | 0  | IF 14 OR LESS INT LEVELS,ELSE 1   | TSK00560 |
| TSK00560 | 0  | IF STANDARD,ELSE 1                | TSK00570 |
| TSK00570 | 1  | IF NO UTILITIES,ELSE 1            | TSK00580 |
| TSK00580 | 1  | IF NO TRACE,ELSE 1                | TSK00590 |
| TSK00590 | 1  | IF NO ADDR.STOP,ELSE 1            | TSK00600 |
| TSK00600 | 1  | IF NO DISK DUMP,ELSE 1            | TSK00610 |
| TSK00610 | 1  | 1 SYS. GEN. FUNC. INCLUDED 0 NONE |          |

|      |     |      |     |              |             |          |
|------|-----|------|-----|--------------|-------------|----------|
| BDT1 | EQU | DT5  | DT1 | IF NO BACKUP | OR NOT USED | TSK65020 |
| BDT2 | EQU | DT2  | DT2 | IF NO BACKUP | OR NOT USED | TSK65030 |
| BDT3 | EQU | DT3  | DT3 | IF NO BACKUP | OR NOT USED | TSK65040 |
| BDT4 | EQU | DT4  | DT4 | IF NO BACKUP | OR NOT USED | TSK65050 |
| BDT5 | EQU | DT1  | DT5 | IF NO BACKUP | OR NOT USED | TSK65060 |
| BDT6 | EQU | DT6  | DT6 | IF NO BACKUP | OR NOT USED | TSK65070 |
| BDT7 | EQU | DT7  | DT7 | IF NO BACKUP | CR NOT USED | TSK65080 |
| BDT8 | EQU | DT8  | DT8 | IF NO BACKUP | CR NOT USED | TSK65090 |
| END  |     | STOP |     |              |             | TSK65100 |
|      |     |      |     |              |             | TSK65110 |

|           |              |                                   |           |          |
|-----------|--------------|-----------------------------------|-----------|----------|
| LVPR1 EQU | 1443         | INTERRUPT LEVEL                   | TSK00410  |          |
| LORC1 EQU | LIST PR..0   | IF 1053,1                         | IF 1443   | TSK00420 |
| SCRC1 EQU | SYSTEM PR..0 | IF 1053,1                         | IF 1443   | TSK00430 |
| SLCRG EQU | WHICH OF 8   | 1053/1816 +S                      | SY/LSLT P | TSK00440 |
| ECPT1 EQU | 0            | IF EAC PR IS 1053,1               | IF 1443   | TSK00450 |
| ECPT2 EQU | 1            | EAC TYPWR COMBINATIONS *1 TO 15 * |           | TSK00460 |
| ECPT3 EQU | 0            | IF EAC TYP ON GPI,ELSE 1          |           | TSK00470 |
| CDINS EQU | 0            | 1 CARD I/O IN SKELETON 0 ELSE     |           | TSK00480 |
| CRDNO EQU | 0            | IF 1 1442, ELSE 1                 |           | TSK00490 |
| CRLF1 EQU | 0            | IF NO OVLP AN.IN.BASIC,ELSE 1.    |           | TSK00500 |
| CRLF2 EQU | 0            | IF NO OVLP AN.IN.EXP.N.,ELSE 1.   |           | TSK00510 |
| PTSKP EQU | 0            | EXITS TO EAC.1,LCCPS UNTIL RDY.   |           | TSK00520 |
| CONIA EQU | 7            | LEVEL OF USER CONS.INT.RTN.       |           | TSK00530 |
| NULEV EQU | 12           | TOTAL NO.LEVELS AT FINAL TSX TIME |           | TSK00540 |
| NKLEV EQU | 0            | IF 14 OR LESS INT LEVELS,ELSE 1   |           | TSK00550 |
| PRICS EQU | 0            | IF STANDARD,ELSE 1                |           | TSK00560 |
| TRORG EQU | 1            | IF NO UTILITIES,ELSE 1            |           | TSK00570 |
| TA01 EQU  | 1            | IF NO TRACE,ELSE 1                |           | TSK00580 |
| TA02 EQU  | 1            | IF NO ADDR.STOP,ELSE 1            |           | TSK00590 |
| TA03 EQU  | 1            | IF NO DISK DUMP,ELSE 1            |           | TSK00600 |
| ONLIN EQU | 1            | 1 SYS. GEN. FUNC. INCLUDED 0 NONE |           | TSK00610 |

|          |     |     |                          |          |
|----------|-----|-----|--------------------------|----------|
| BDT1 EQU | DT5 | DT1 | IF NO BACKUP OR NOT USED | TSK6502J |
| BDT2 EQU | DT2 | DT2 | IF NO BACKUP OR NOT USED | TSK65030 |
| BDT3 EQU | DT3 | DT3 | IF NO BACKUP OR NOT USED | TSK65040 |
| BDT4 EQU | DT4 | DT4 | IF NO BACKUP OR NOT USED | TSK65050 |
| BDT5 EQU | DT1 | DT5 | IF NO BACKUP OR NOT USED | TSK6506J |
| BDT6 EQU | DT6 | DT6 | IF NO BACKUP OR NOT USED | TSK65070 |
| BDT7 EQU | DT7 | DT7 | IF NO BACKUP OR NOT USED | TSK6508J |
| BDT8 EQU | DT8 | DT8 | IF NO BACKUP OR NOT USED | TSK65090 |
|          |     |     |                          | TSK6510J |

```

// JCB
// *LIST OF SYSTEM DIRECTOR EQUATE CARDS
// *ASM SDEQU
// *ASM SDEQU
// *SAVE SYMBOL TABLE

```

| NUL   | LEV | ABS | 12 | NUMBER OF LEVELS USED     | SYD       |
|-------|-----|-----|----|---------------------------|-----------|
| USE0  | EQU |     | 1  | 1-LEVEL USED              | SYD000020 |
| USE1  | EQU |     | 1  | 1-LEVEL USED              | SYD000020 |
| USE2  | EQU |     | 1  | 1-LEVEL USED              | SYD000040 |
| USE3  | EQU |     | 1  | 1-LEVEL USED              | SYD000050 |
| USE4  | EQU |     | 1  | 1-LEVEL USED              | SYD000060 |
| USE5  | EQU |     | 1  | 1-LEVEL USED              | SYD000070 |
| USE6  | EQU |     | 1  | 1-LEVEL USED              | SYD000080 |
| USE7  | EQU |     | 1  | 1-LEVEL USED              | SYD000090 |
| USE8  | EQU |     | 1  | 1-LEVEL USED              | SYD000100 |
| USE9  | EQU |     | 1  | 1-LEVEL USED              | SYD000110 |
| USE10 | EQU |     | 1  | 1-LEVEL USED              | SYD000120 |
| USE11 | EQU |     | 1  | 1-LEVEL USED              | SYD000130 |
| USE12 | EQU |     | 0  | 1-LEVEL USED              | SYD000140 |
| USE13 | EQU |     | 0  | 1-LEVEL USED              | SYD000150 |
| USE14 | EQU |     | 0  | 1-LEVEL USED              | SYD000160 |
| USE15 | EQU |     | 0  | 1-LEVEL USED              | SYD000170 |
| USE16 | EQU |     | 0  | 1-LEVEL USED              | SYD000180 |
| USE17 | EQU |     | 0  | 1-LEVEL USED              | SYD000190 |
| USE18 | EQU |     | 0  | 1-LEVEL USED              | SYD000200 |
| USE19 | EQU |     | 0  | 1-LEVEL USED              | SYD000210 |
| USE20 | EQU |     | 0  | 1-LEVEL USED              | SYD000220 |
| USE21 | EQU |     | 0  | 1-LEVEL USED              | SYD000230 |
| USE22 | EQU |     | 0  | 1-LEVEL USED              | SYD000240 |
| USE23 | EQU |     | 0  | 1-LEVEL USED              | SYD000250 |
| NB00  | EQU |     | 0  | 1-LEVEL USED              | SYD000260 |
| NB01  | EQU |     | 0  | 1-LEVEL USED              | SYD000270 |
| NB02  | EQU |     | 0  | 1-LEVEL USED              | SYD000280 |
| NB03  | EQU |     | 0  | 1-LEVEL USED              | SYD000290 |
| NB04  | EQU |     | 0  | 1-LEVEL USED              | SYD000300 |
| NB05  | EQU |     | 2  | 1-HIGHEST ILSW BIT = USED | SYD000310 |
| NB06  | EQU |     | 2  | 1-HIGHEST ILSW BIT = USED | SYD000320 |
| NB07  | EQU |     | 1  | 1-HIGHEST ILSW BIT = USED | SYD000330 |
| NB08  | EQU |     | 2  | 1-HIGHEST ILSW BIT = USED | SYD000340 |
| NB09  | EQU |     | 3  | 1-HIGHEST ILSW BIT = USED | SYD000350 |
| NB10  | EQU |     | 2  | 1-HIGHEST ILSW BIT = USED | SYD000360 |
| NB11  | EQU |     | 2  | 1-HIGHEST ILSW BIT = USED | SYD000370 |
| NB12  | EQU |     | 2  | 1-HIGHEST ILSW BIT = USED | SYD000380 |
| NB13  | EQU |     | 1  | 1-HIGHEST ILSW BIT = USED | SYD000390 |

```

// JCB
// *LIST OF SYSTEM DIRECTOR EQUATE CARDS
// *ASM SDEQU
// *ASM SDEQU
// *SAVE SYMBOL TABLE

```

| NUL   | LEV | ABS | 12 | NUMBER OF LEVELS USED     | SYD      |
|-------|-----|-----|----|---------------------------|----------|
| USE00 | EQU |     | 1  | 1-LEVEL USED              | SYD00020 |
| USE01 | EQU |     | 1  | 0-NOT USED                | SYD00020 |
| USE02 | EQU |     | 1  | 0-NOT USED                | SYD00040 |
| USE03 | EQU |     | 1  | 0-NOT USED                | SYD00050 |
| USE04 | EQU |     | 1  | 0-NOT USED                | SYD00060 |
| USE05 | EQU |     | 1  | 0-NOT USED                | SYD00070 |
| USE06 | EQU |     | 1  | 0-NOT USED                | SYD00080 |
| USE07 | EQU |     | 1  | 0-NOT USED                | SYD00090 |
| USE08 | EQU |     | 1  | 0-NOT USED                | SYD00100 |
| USE09 | EQU |     | 1  | 0-NOT USED                | SYD00110 |
| USE10 | EQU |     | 1  | 0-NOT USED                | SYD00120 |
| USE11 | EQU |     | 1  | 0-NOT USED                | SYD00130 |
| USE12 | EQU |     | 1  | 0-NOT USED                | SYD00140 |
| USE13 | EQU |     | 1  | 0-NOT USED                | SYD00150 |
| USE14 | EQU |     | 1  | 0-NOT USED                | SYD00160 |
| USE15 | EQU |     | 1  | 0-NOT USED                | SYD00170 |
| USE16 | EQU |     | 1  | 0-NOT USED                | SYD00180 |
| USE17 | EQU |     | 0  | 0-NOT USED                | SYD00190 |
| USE18 | EQU |     | 0  | 0-NOT USED                | SYD00200 |
| USE19 | EQU |     | 0  | 0-NOT USED                | SYD00210 |
| USE20 | EQU |     | 0  | 0-NOT USED                | SYD00220 |
| USE21 | EQU |     | 0  | 0-NOT USED                | SYD00230 |
| USE22 | EQU |     | 0  | 0-NOT USED                | SYD00240 |
| USE23 | EQU |     | 0  | 0-NOT USED                | SYD00250 |
| NB00  | EQU |     | 0  | 0-NOT USED                | SYD00260 |
| NB01  | EQU |     | 0  | 0-NOT USED                | SYD00270 |
| NB02  | EQU |     | 0  | 0-NOT USED                | SYD00280 |
| NB03  | EQU |     | 0  | 0-NOT USED                | SYD00290 |
| NB04  | EQU |     | 0  | 0-NOT USED                | SYD00300 |
| NB05  | EQU |     | 2  | 1+HIGHEST ILSW BIT = USED | SYD00310 |
| NB06  | EQU |     | 2  | 1+HIGHEST ILSW BIT = USED | SYD00320 |
| NB07  | EQU |     | 1  | 1+HIGHEST ILSW BIT = USED | SYD00330 |
| NB08  | EQU |     | 2  | 1+HIGHEST ILSW BIT = USED | SYD00340 |
| NB09  | EQU |     | 3  | 1+HIGHEST ILSW BIT = USED | SYD00350 |
| NB10  | EQU |     | 2  | 1+HIGHEST ILSW BIT = USED | SYD00360 |
| NB11  | EQU |     | 2  | 1+HIGHEST ILSW BIT = USED | SYD00370 |
| NB12  | EQU |     | 2  | 1+HIGHEST ILSW BIT = USED | SYD00380 |
| NB13  | EQU |     | 1  | 1+HIGHEST ILSW BIT = USED | SYD00390 |

[illegible]

NITF1 EQU  
NITF2 EQU  
ICLL1 EQU  
ICLL2 EQU  
ITCLS EQU  
TBASE EQU  
CBASE EQU  
TIMEL EQU  
TIMED EQU  
NCRSP EQU  
VCRSP EQU  
NUQL EQU  
DUMPL EQU  
CPMCI EQU  
TISHA EQU  
TIMES EQU

16  
0  
/04JF  
/FFFF  
1  
-123  
1  
/0000  
/03E8  
12, NO RESP  
7000  
6  
0  
1  
33  
1

NO. COUNT SUBRS. GROUP 1 SYD0081J  
NO. COUNT SUBRS. GROUP 2 SYD0082J  
INT. CORELCAD LEVEL MASK SYD0083J  
INT. CORELOAD LEVEL MASK SYD0084J  
1-ITC USED 0-NOT USED SYD0085J  
CLOCK BASE=MILSEC\*TBASE SYD0086J  
COUNT BASE=MILS\*TBASE\*CBASE SYD0087J  
TIMER C MILS\*TBASE SYD0088J  
TIMER C MILS\*TBASE SYD0089J  
TIME, VALUE BETW 1-127 M6 SYD00895  
ADDR. 1ST WORD VARIABLE COR SYD0090J  
NUMBER OF QUEUE ENTRIES SYD0091J  
1-EAC DUMP USED 0-NOT USED SYD0092J  
1-ITC RESETS 0-USER RESETS SYD0093J  
PERIOD FOR TIME SHARING SYD0094J  
1-TSC UXED 0-TSC NOT USED

## APPENDIX IV

### OUTPUT INTERFACE CALIBRATION

The output interface designed controls the power by controlling the firing angle of thyristor. When reference voltage is zero, the power is available for the complete cycle and when it is five volts, the firing angle is  $180^\circ$  and hence no power.

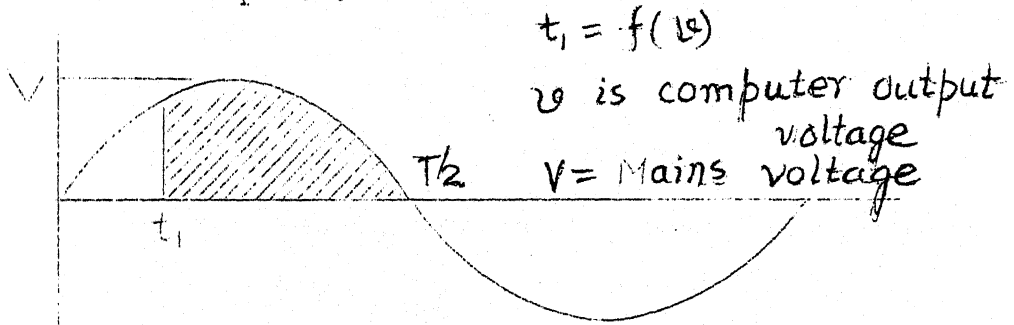


Fig. IV.1: Wave form across load.

$$t_1 = \frac{v}{5} \times \frac{T}{2}$$

$$P = \frac{2}{T} \int_{\frac{Tv}{10}}^{T/2} A^2 \sin^2 \frac{2\pi}{T} t \, dt$$

$$= \frac{2A^2}{T} \int_{\frac{Tv}{10}}^{T/2} \sin^2 \frac{2\pi}{T} t \, dt$$

$$= \frac{A^2}{T} \int_{\frac{Tv}{10}}^{T/2} (1 - \cos \frac{4\pi}{T} t) \, dt$$

$$= \frac{A^2}{T} \left[ t - \frac{T}{4\pi} \cdot \sin \frac{4\pi}{T} t \right]_{\frac{Tv}{10}}^{T/2}$$



$$\begin{aligned}
P &= \frac{A^2}{T} \left[ \left( \frac{T}{2} - \frac{T \cdot v}{10} \right) - \frac{T}{4\pi} (\sin \pi - \sin \frac{\pi v}{5}) \right] \\
&= A^2 \left( \frac{1}{2} - \frac{v}{10} \right) - \frac{A^2}{4\pi} \sin \frac{\pi v}{5} \\
&= A^2 \left( \frac{1}{2} - \frac{v}{10} \right) - \frac{A^2}{4\pi} \left( \frac{\pi v}{5} - \frac{(\pi v)^3}{3!} + \frac{(\pi v)^5}{5!} \right) \\
&= A^2 \left[ \frac{1}{2} - v \left( \frac{1}{10} - \frac{1}{20} \right) - \frac{\pi^2 v^3}{24} + \text{higher order terms} \right] \\
&= A^2 \left[ \frac{1}{2} - \frac{v}{20} - \frac{\pi^2 v^3}{24} + \text{higher order terms} \right]
\end{aligned}$$

The above analysis shows that polynomial may be fitted for the calibrated datas.

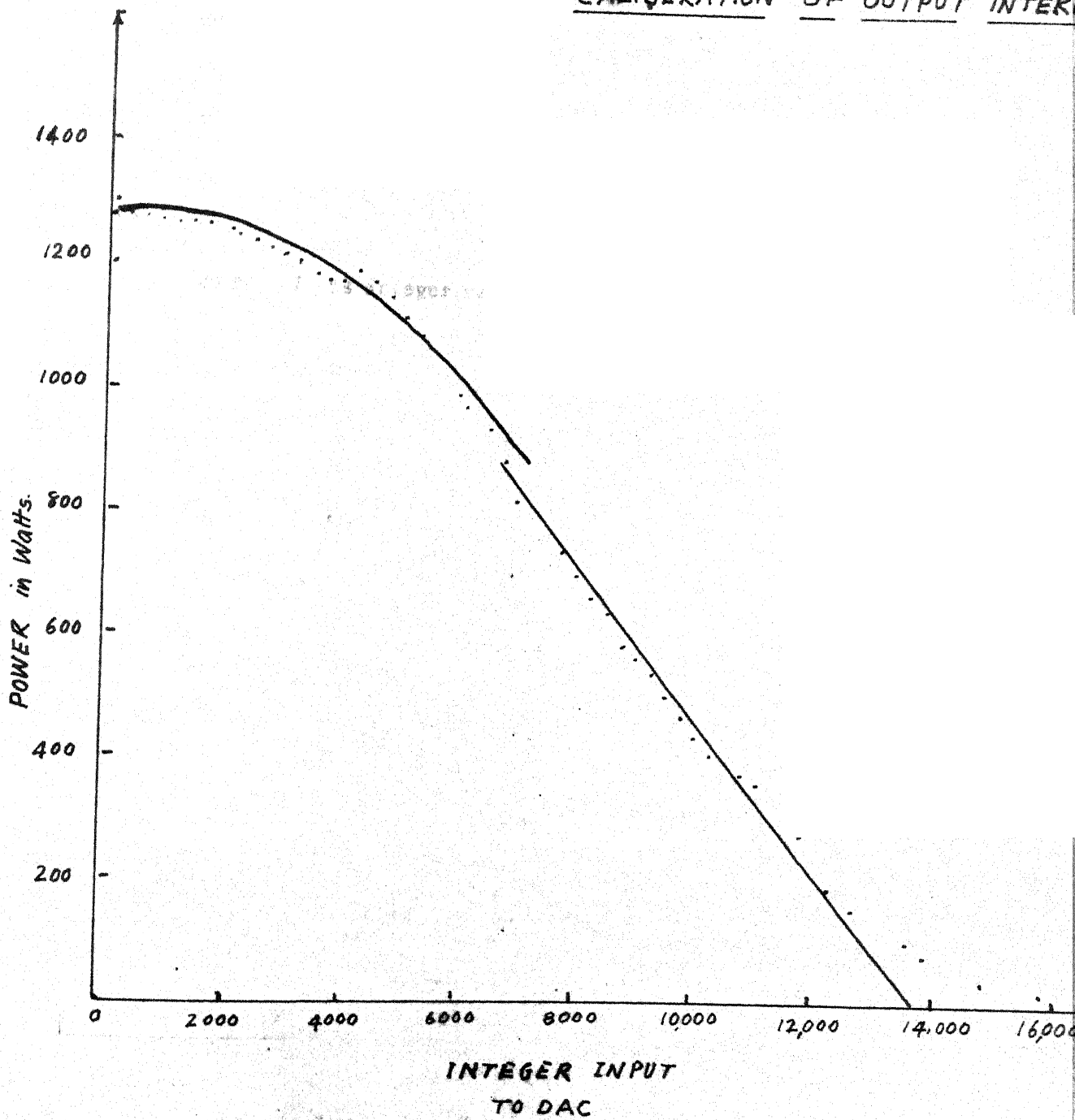
#### Output Interface Calibration :

The calibration datas have been divided into two groups for better polynomial fitting ( so as to get minimum average error for each group). The power verses integer number plot is shown in fig. IV-2 and the two curves are clearly shown.

The program is written for this purpose to sense the data switch status after pressing start and convert the value to analog form using DAC and ADA. The converted analog value is fed to signal input terminals of output interface.

The different signal voltages are given to output interface varying the data switches status and the output power is noted using a wattmeter. The polynomials fitted for two groups of

CALIBRATION OF OUTPUT INTER



datas are the following :

$$P = - 8.1489I + 13754.14$$

when  $I \leq 820$

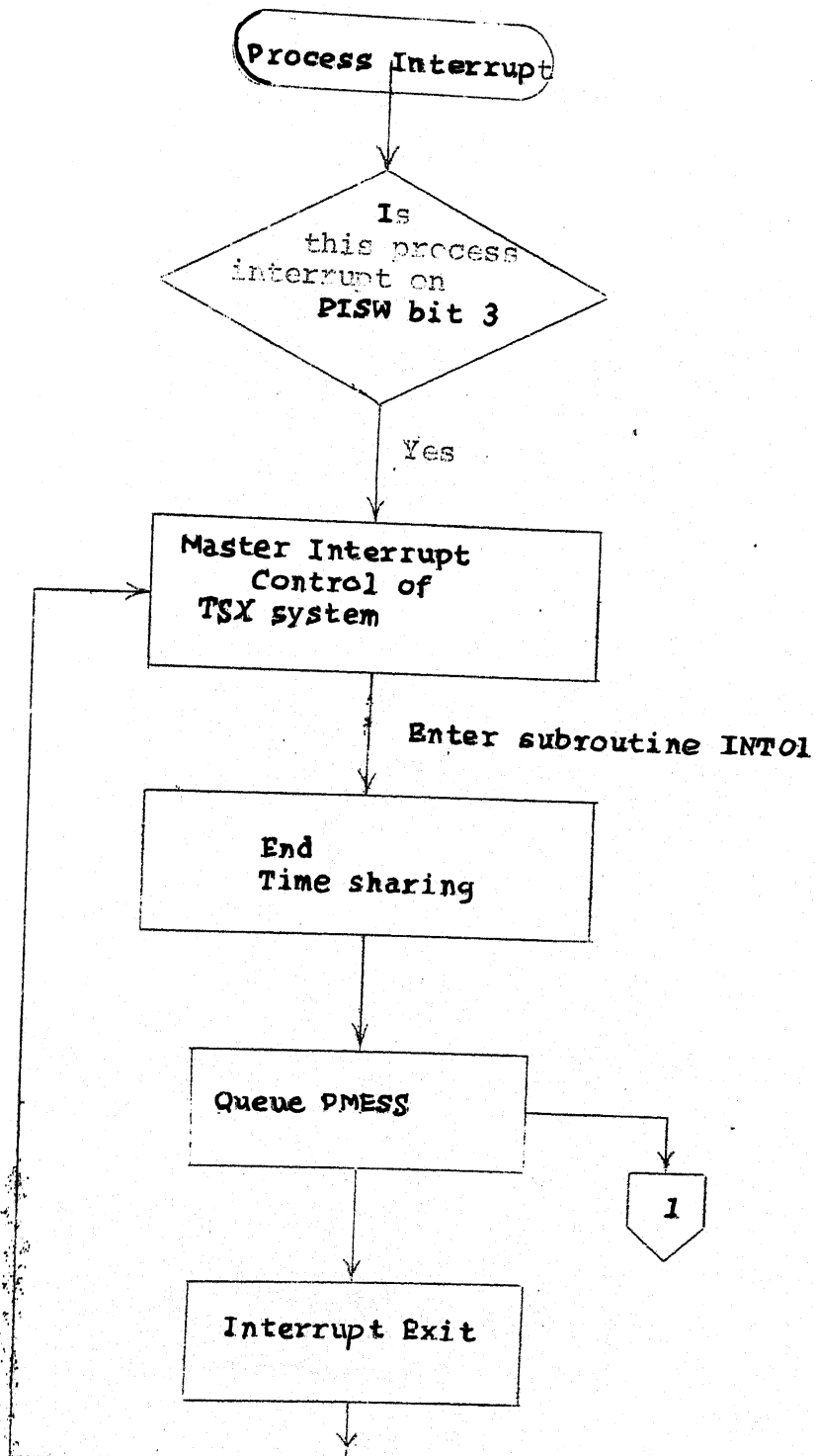
which gives maximum error  $\leq 4.97\%$  and

$$P = -0.0288 I^2 + 48.8934 I - 13972.0472$$

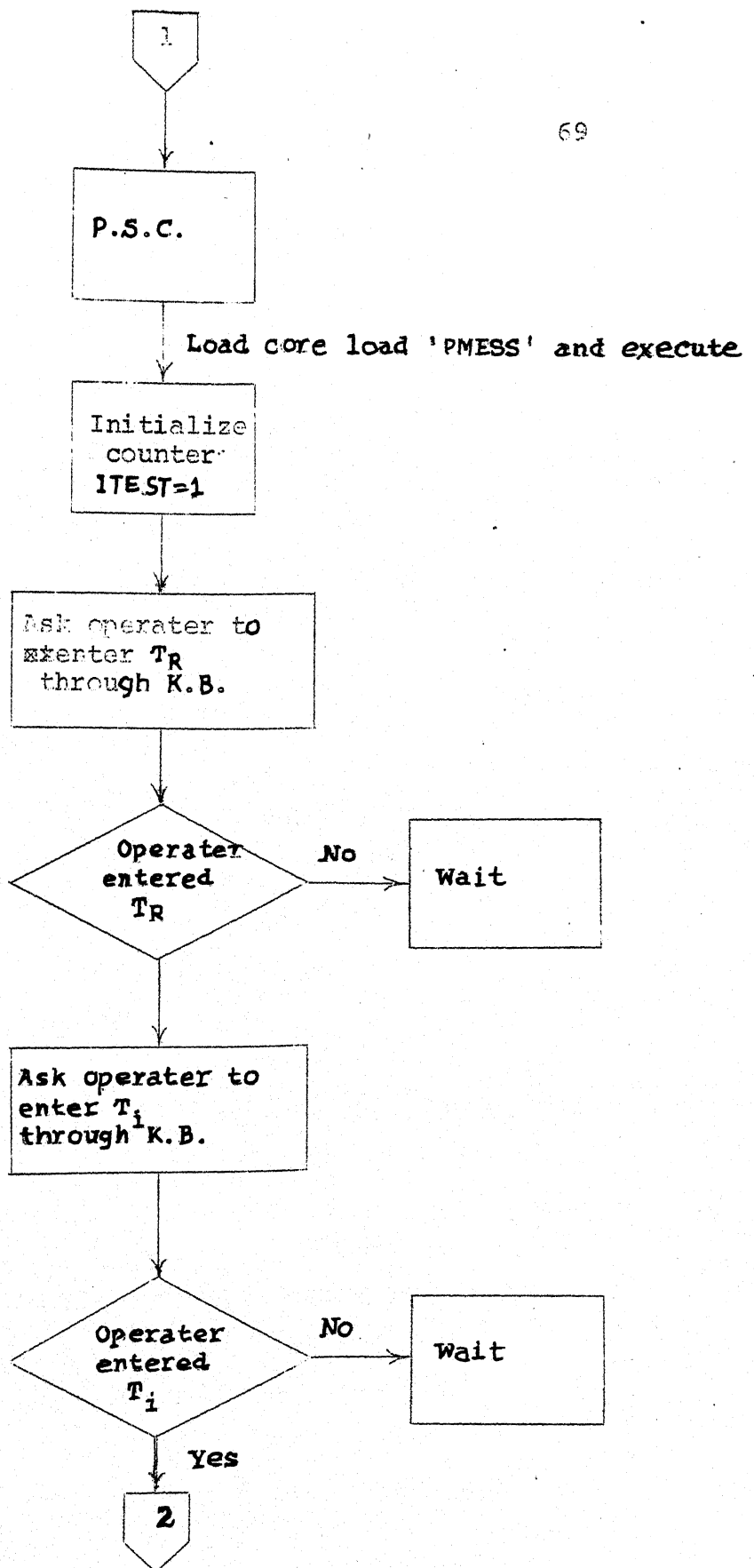
when  $I \geq 820$

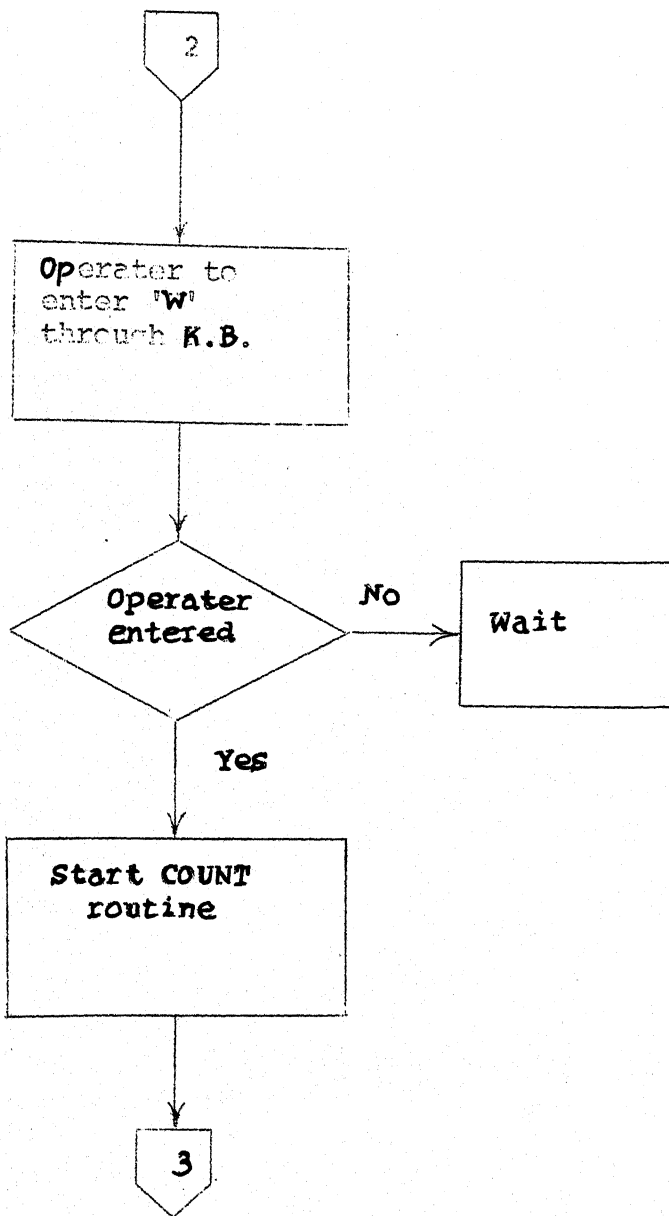
max. error : 4.66%

where  $I$  is integer value fed through datas switches.

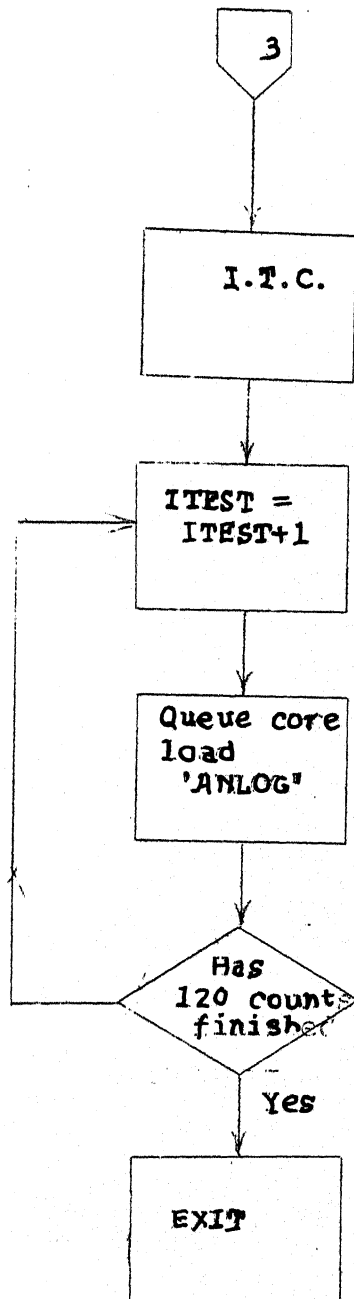


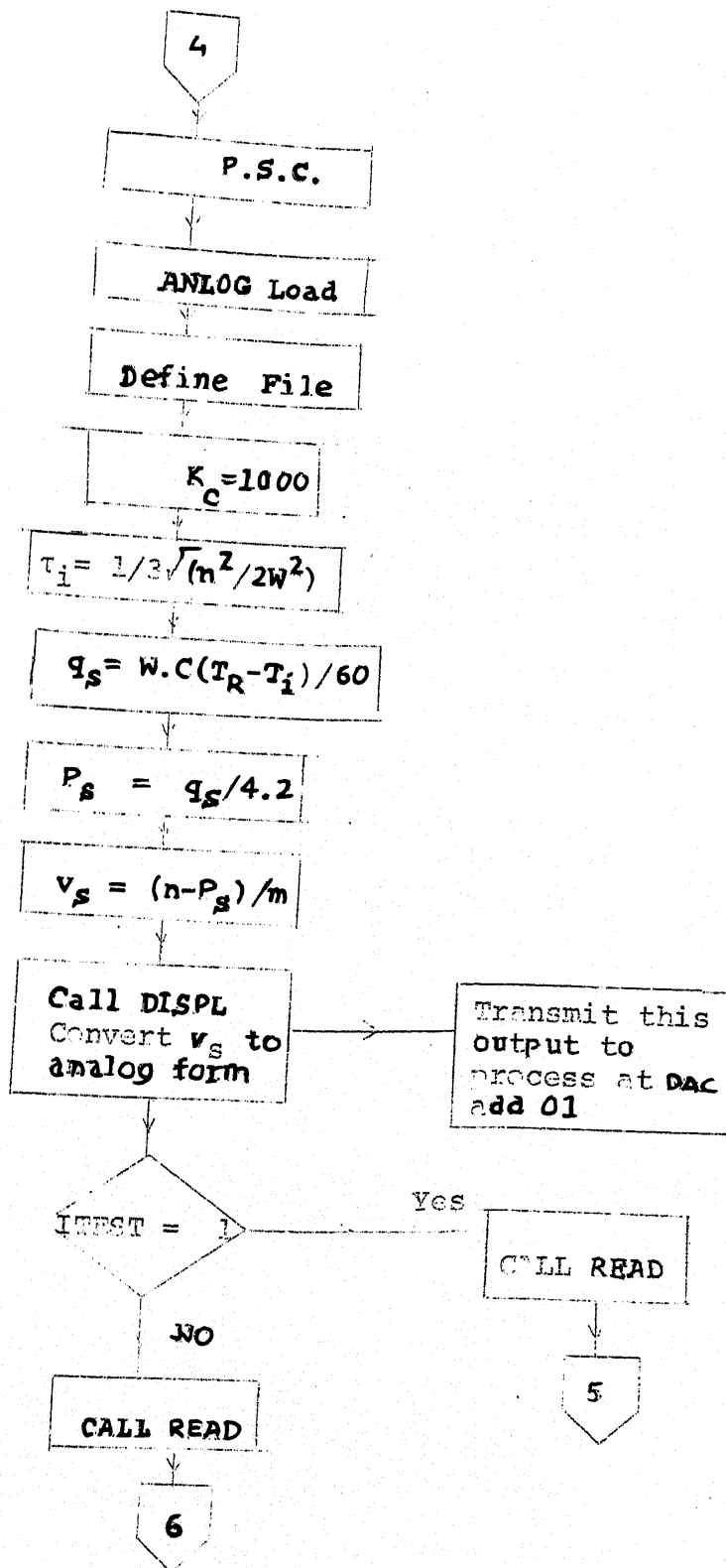
SERVICING ROUTINE FOR PISW BIT 3





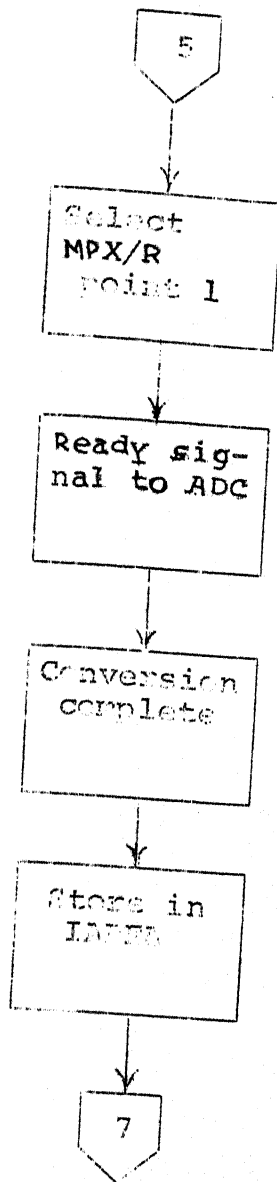
ROUTINE 'OMESS' PRINTS MESSAGE TO OPERATE



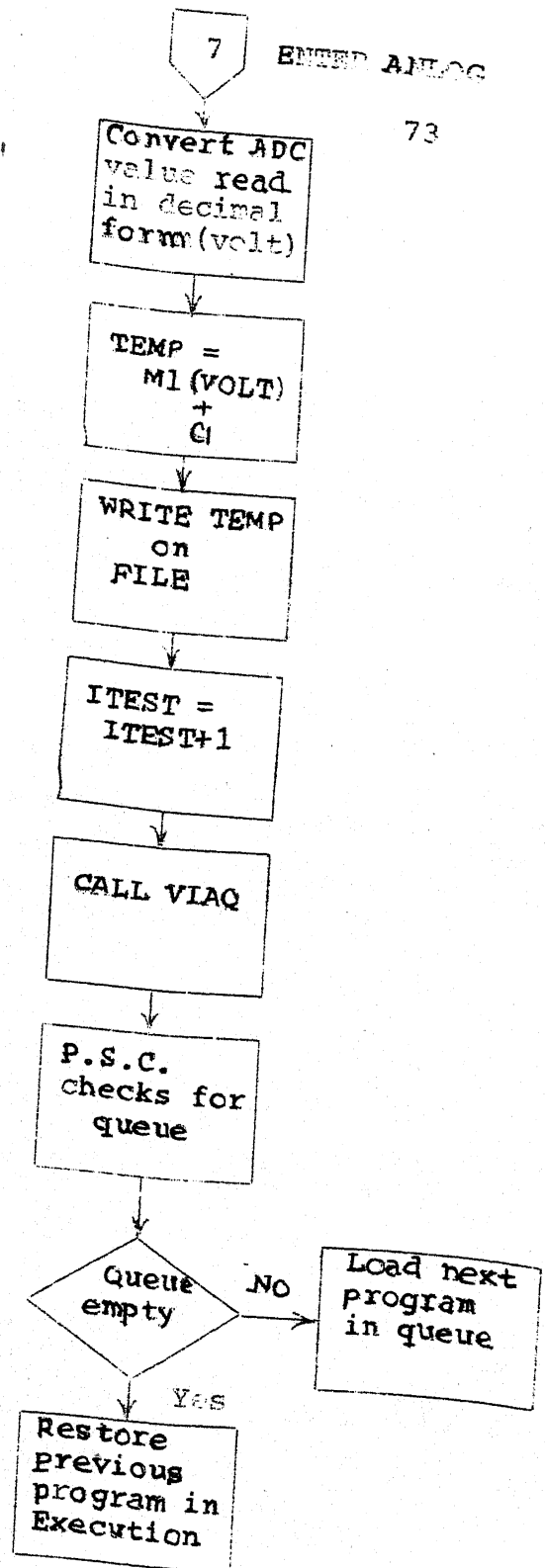


ANALOG ROUTINE



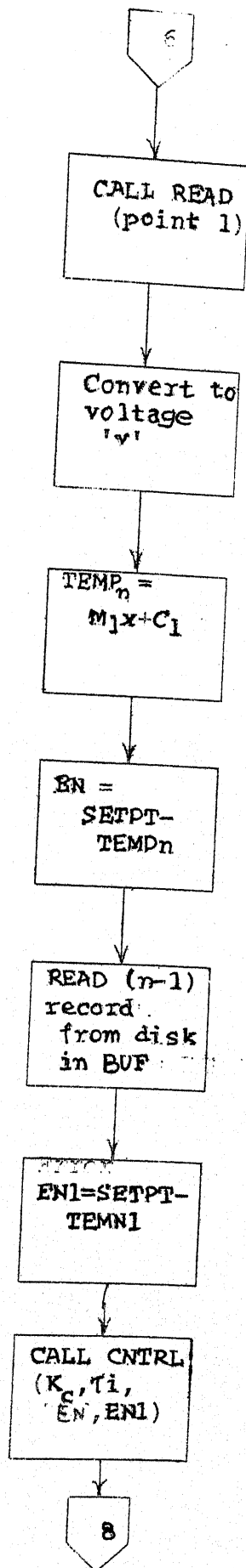


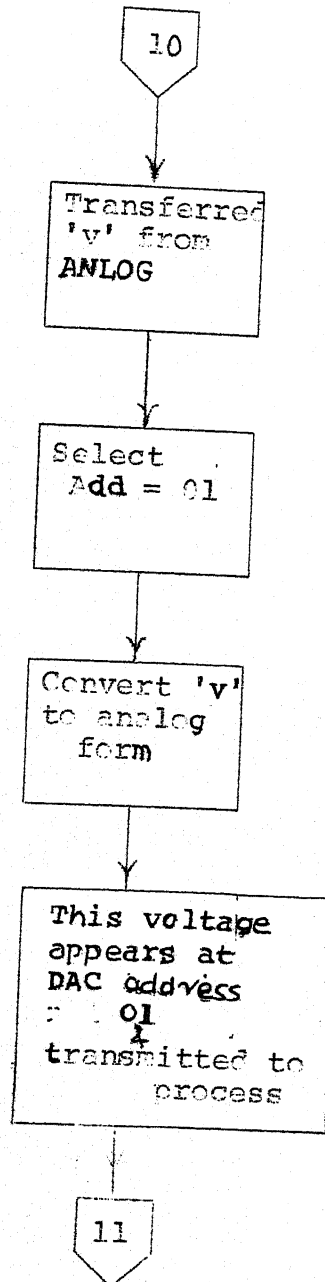
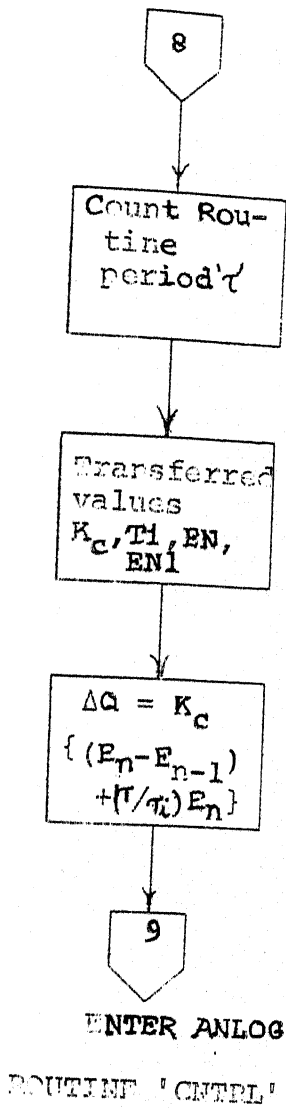
ROUTINE 5

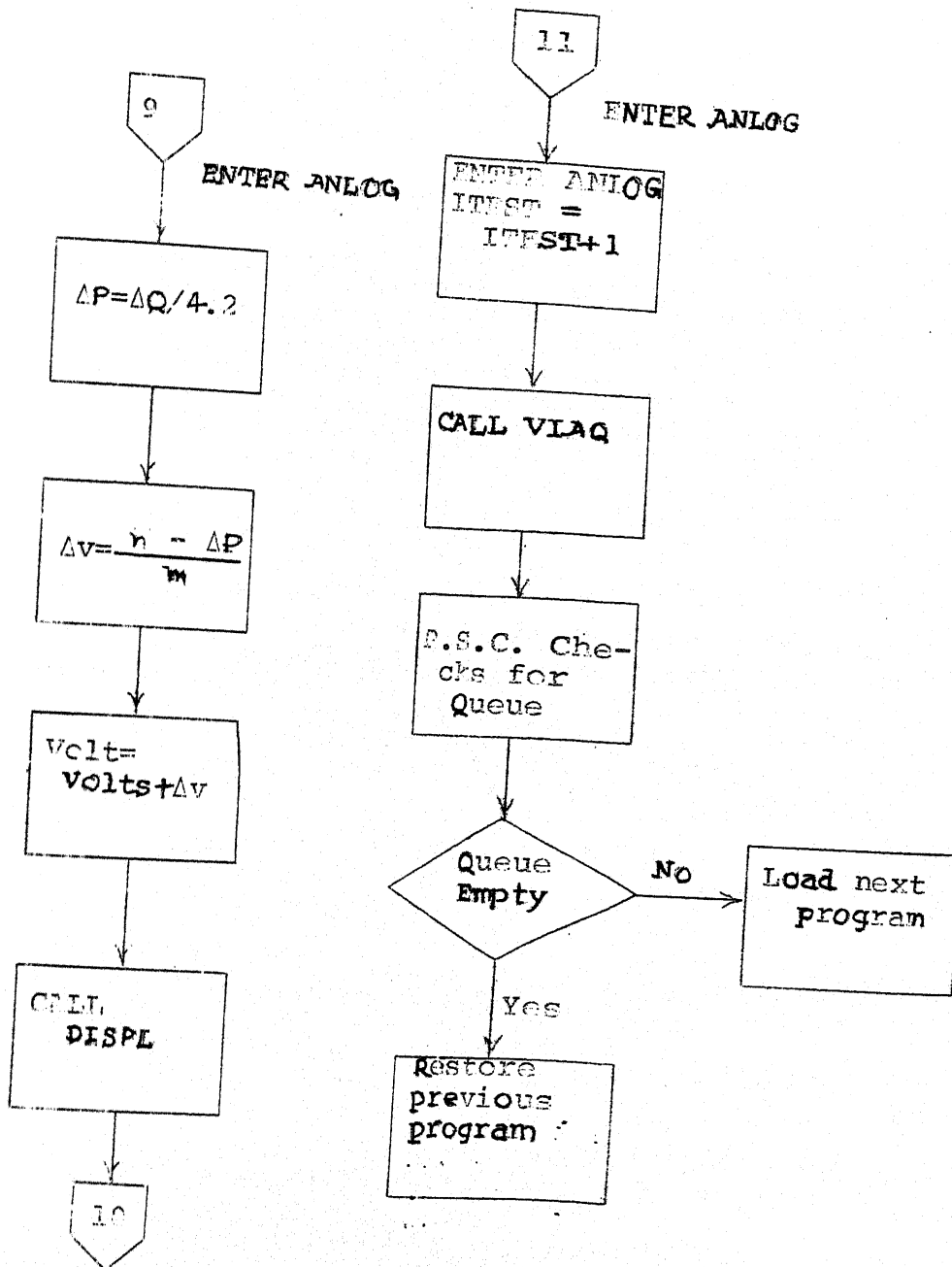


ENTER ANALOG

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